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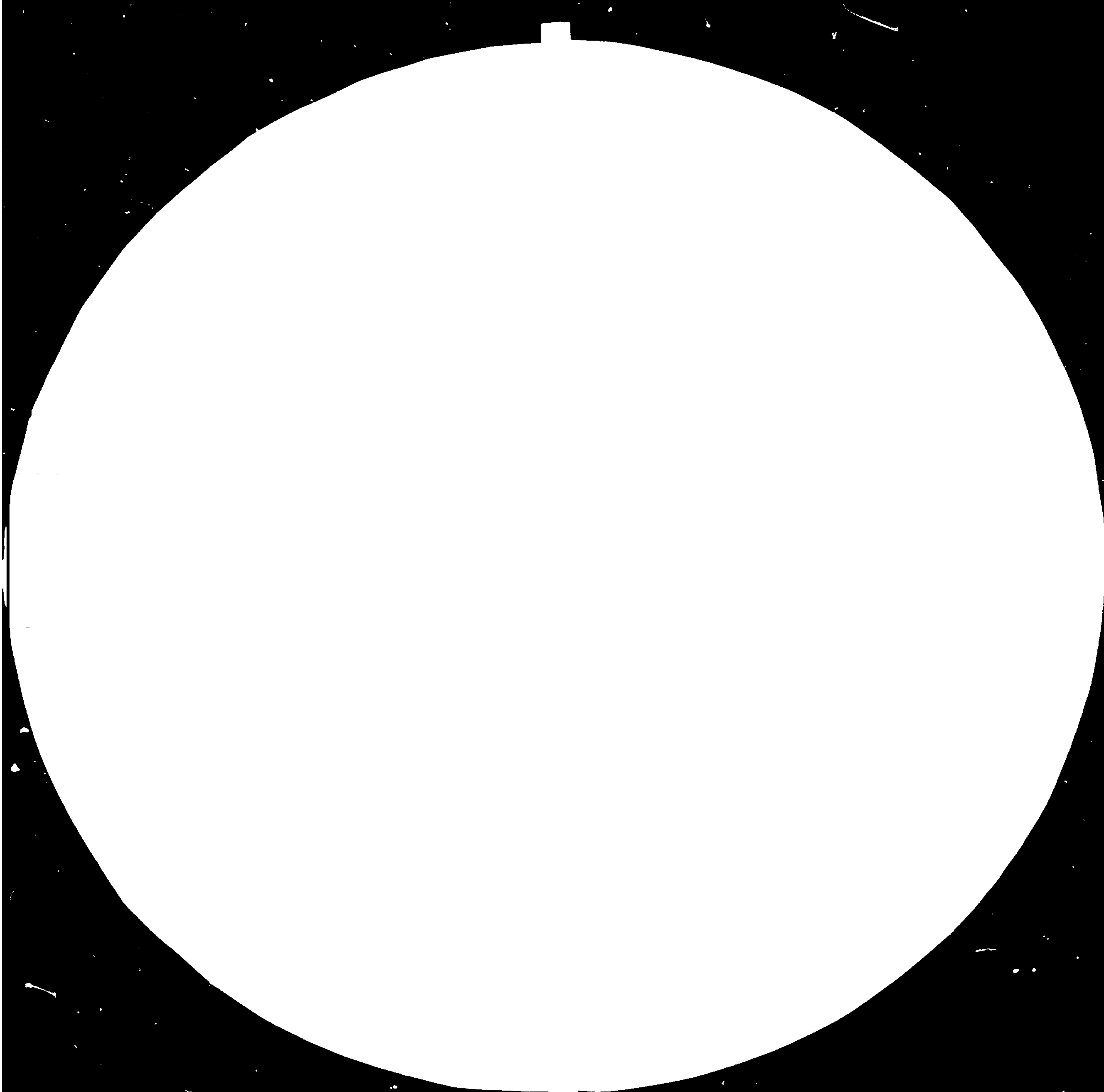

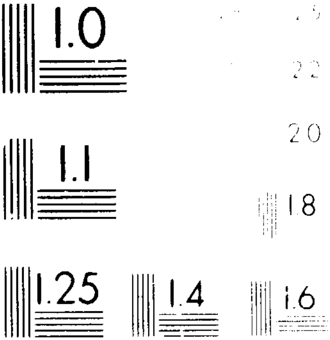
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July 1984
ENGLISH

COAL GASIFICATION

INDIA

DP/IND/80/004

Technical Report[x]

Mission from 19-27 April 1984

Prepared for the Government of India
by the United Nations Industrial Development Organization,
acting as executing agency
for the United Nations Development Programme

Based on the work of B. Konrád

Consultant on data collection and evaluation

United Nations Industrial Development Organization

Vienna

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CONTENTS

Summary

From 19 to 27 April 1984 I visited the Regional Research Laboratory in Hyderabad as a consultant on the coal gasification project funded by the UNDP. The most important activities of my mission were as follows:

- Visit to and inspection of a pilot plant for gasification of coal.
- Visit to and inspection of laboratories and acquainting with supporting studies on the project of gasification.
- Giving of lectures on gasification and discussion about this subject.
- Discussion with the workers attending the pilot plant about the problems of fixed bed pressure gasification including the evaluation of coal for gasification.
- Discussion about and recommendation for data collection and evaluation of pilot-plant experiments.
- Assistance in suggesting the optimum programme of tests with gasifying Indian coals.
- Discussion about and assistance in suggesting the training of the respective workers in association with the realization of the gasification programme.

The inspection showed that the pilot plant was quite well ready for gasification and equipped with the measuring technique that was sufficient for data collection and their further evaluation and thus also for judging the suitability of coals under investigation for gasification.

The discussed programme of experiments including the verification of the suggested types of coals is real and can be fulfilled in the presupposed date (November 1985), including the preparation of the final report.

The analytical equipment of the laboratories for the evaluation of coal, ash, and gas is sufficient.

In the discussion the principles of determining the reactivity towards CO_2 under atmospheric pressure were explained, the same concerns the determination of the sintering point of ash developed by the Fuel Research Institute, Prague.

The suggested trainings of the respective workers should further deepen the knowledge from the field of planning and evaluating the gasification tests of coals, acquaint with experience from the field of researches into the machinery of gasifiers and improve the attendance of a full-scale gasification unit.

I wish to express my sincere thanks to the national project Director and the colleagues of RRL Hyderabad for the open information and free discussion of problems connected with future work on the project.

The organization of my visit was excellent and the hospitality and kind assistance are very much appreciated.

Time table of the mission

Date	Day	Action
April		
16	Mon	Travel Prague - Vienna Briefing at UNIDO (Dr. M. Maung)
17/18	Tue/Wed	Travel Vienna - Delhi
18	Wed	Morning: Briefing at UNDP (Dr. M.K.Hussein) Afternoon: Travel Delhi- Hyderabad
19	Thu	Morning: Visit to the pilot plant Afternoon: Visit to the laboratories
23	Mon	Morning: Discussion on gasification Afternoon: Coal reactivity, sintering of ash

Date	Day	Action
April		
24	Tue	Morning: Measurements for evaluating the pilot-plant gasification tests Afternoon: Discussion about the methodology of preparation and performing of tests
25	Wed	Morning: Data collection and evaluation Afternoon: Mass balances of the gasification process
26	Thu	Morning: Lectures: Importance of coal quality to fixed bed pressure gasification The influence of pressure on gasification Gasifying agent Afternoon: Discussion about the programme of pilot-plant tests
27	Fri	Morning: Lecture: Concept of pressure gasification plants in Czechoslovakia Afternoon: Discussion about the evaluation of coals by measuring the reactivity and TGA Training programme (Rao, Anjaneyulu, Reddy, Murty) Evening: Travel Hyderabad - Delhi
29	Sun	Travel Delhi - Prague via Frankfurt

Report of findings, discussions and recommendations

1. Pilot plant

The pilot plant consists of the following main parts:

- Store and preparation of coal
- Oxygen plant
- Boiler house
- Gasification of coal
- Purification of gas
- Separation and storage of liquid products

The core of the installation forms a pressure gasification unit the main part of which is a double-shell pressure gasifier of 1.1 m internal diameter.

In the space between the internal and external shells of the gasifier steam is generated during gasification and admixed to the produced crude gas. The coal for gasification is charged to a coal bunker above the gasifier and from here it is led to a coal lock placed above the gasifier. From the coal lock the coal falls through a simple chute into the reactor. The reactor is equipped with a crude gas outlet, the layer of fuel is carried by a step rotary grate placed in the bottom part of the shaft and intended for the distribution of the gasifying agent and for the removal of ash. The grate revolutions and thus also the quantity of ash removed from the gasifier can be changed. The ash from the gasifier falls into the ash lock and from here to the ash pocket. The end closures of both the coal lock and the ash lock are manually operated. The crude gas is led to a waste heat boiler which is also designed as a scrubber cooler. Here the gas is cooled partly by spraying with circulating phenol water, partly its heat is used for the generation of steam of a pressure of 2.8 bar. From the bottom of the waste heat boiler a tar and phenol water mixture is drawn off to separating tanks. The gas goes forward to the after cooler in which it is cooled and at the same time further phenol water and oil are separated and drawn off to the separating tanks. Thus treated gas is either burnt in a flare or purified (liberated from CO_2 and H_2S) by washing with hot potash. This installation consists of the prewasher, the adsorber, the tower for the wash solution regeneration, the cooler, and the water separator. By using the hot potash the CO_2 and H_2S contents should be reduced to 2 vol.% and 200 $mg.m^{-3}$ respectively.

2. Data collection and evaluation

On the basis of the discussion with the respective workers of the RRL Hyderabad, the collection of the following data was recommended to evaluate the operation.

2.1 Coal

Sampling: from each coal feeding
rough sample 100 kg in 8 hours (per 1 shift)

From the rough sample to prepare: a shift sample 30 - 50 kg
a partial sample for a daily analysis 3 - 5 kg

For the shift sample to determine: the screening test (wt.%)
above 25 mm
15 - 25 mm
10 - 15 mm
6 - 10 mm
below 6 mm
bulk density $kg.m^{-3}$
analysis : water content W_t^r wt.%
ash content (dry) A^d wt.%

Note: The screening test and the bulk density may also be prepared only from daily samples. Of course, in this case such shift samples should be taken so that for the given determinations 30 - 50 kg of coal were available.

Daily sample: prepared by mixing partial shift samples
analysis:

water content W_t^r	wt.%
ash content A^d	wt.%
combustible matter	wt.%
volatile matter	wt.%
fixed carbon	wt.%

elementary analysis of the combustible matter C, H, S, O, N wt.%

ash fusion points ($^{\circ}C$) t_A , t_B , t_C

Note: In the steady operation of the installation a mixed sample may be prepared from shift samples, representing the whole evaluated section of the test, and analysed in the same way as given in the case of the daily sample.

Sample per the section of the test: the analyses recommended for the daily test should be completed by

- the determination of the chemical composition of ash wt.% : SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3, TiO_2, K_2O, Na_2O, SO_3 and by
- the determination of water, tar, semi-coke, and gas (Gray King assay)

In determining the mass balances of the gasification process, the quantity of gasified coal represents the basic item.

Owing to this, it was agreed to pay considerable attention to the quantity of coal

a) from the volume of the coal bunker and to the bulk density

b) from the volume and number of coal locks and to the bulk density

It was stated that for the most accurate method of evaluating the quantity of gasified coal, i.e. weighing, the pilot plant did not display real conditions.

2.2 Oxygen

Analysis : O_2 vol.% - once a day
Measurements : temperature, pressure - according to records
Quantity : (measured with an orifice) - by planimetering the registered record
- the use of a diagram for measuring the oxygen flow

2.3 Air

Measurements : temperature, pressure
Amount : (measured with an orifice) - by planimetering the registered record
- the use of a diagram for measuring the air flow

2.4 Gasification steam

Measurement : temperature - according to a record
pressure - manually recorded
Quantity : (measured with an orifice) - by planimetering the registered record
- the use of a diagram for measuring the steam flow

2.5 Gasification ratio

By calculating from the amounts of oxygen and steam

2.6 Jacket feed water

The quantity will be determined

2.7 Water to waste heat boiler

It will not be determined

2.8 Crude gas

Analyses : determination of CO_2, O_2 once per hour for checking the operation

Continuous analyses : mass spectrometer, gas-chromatograph and IR - analyzers

For analysing immediate samples the Orsat instrument is also available for the determination (vol.%) of: CO_2, O_2, H_2, N_2, CO, CH_4, CnHm, C_2H_6 (C_3H_8, C_4H_{10}, C_5H_{12}), H_2S

Measurements : quantity (measured with an orifice) - by planimetering the record
- the use of a diagram for measuring the crude gas flow

temperature - according to a record
pressure - according to a record

Note: In evaluating, the gas consumed for pressurizing a coal lock should also be under consideration. Its quantity is determined from the volume of gas in the coal lock and from the coal lock filling frequency. This quantity attains approximately 4 % of the overall gas production in the large-scale installations in Czechoslovakia.

2.9 Ash

A partial sample should be taken from each de-ashing.
Preparation of a shift sample (in 8 hours) 3 - 5 kg
Analysis : ash
unburnt residue
C (H) in the unburnt residue

The ash quantity should be calculated according to the unburnt residue content in ash and according to the ash content in coal.

The adjusted value of grate revolutions should be recorded.

2.10 Tar, oil, phenol water

Their quantities are measured according to the state in the storage tanks for by-products.

Note: The quantity will evidently be read off for a longer period of the installation operation, for example, for the whole 7-10 days test. The values obtained are recommended to be compared with the results of the Gray King carbonization test.

Analysis : tar, oil - elementary analysis C, H, /O, N, S/
distillation curve
phenol water - contents of phenols
ammonia content
contents of fatty acids

2.11 Further measurements carried out in the gasification unit

Temperatures:

Gasifier top temperature - once per hour
manually recorded
ash lock - recorded
gasifier outlet - recorded
waste heat boiler outlet - recorded
steam - oxygen mixture - recorded

Pressures:

waste heat boiler outlet - manually recorded

3. Choice of test sections

The data given in chapter 2 should be processed according to the programme of tests, always for the time section with the same or similar operating parameters.

Thus, for example, for the test 1 (chapter 5)

a) gasification with steam and air at 1.5 MPa
b) gasification with steam and oxygen at 1.5 MPa
c) gasification with steam and oxygen at 2.0 MPa
d) gasification with steam and oxygen at 2.4 MPa

The evaluation should not cover, for example, the operation at a considerably lower load than intended for the test or putting out of operation caused by technological difficulties or necessity to repair the installation.

For a guaranty operation of the full-scale installation confirming the output of the gasification installation in processing the tested coal, the time section 3 x 24 hours has been determined.

4. Calculations of balances

The calculations of the mass balances of the main elements found in the gasification process permit to check the accuracies of measurements during the gasification process.

4.1 Mass balances

Calculated are carbon, hydrogen, and oxygen balances. The values are usually given in kg of the element per time unit as well as the relative amounts expressed in % are given.

4.1.1 Balance of carbon

Inlet

C in coal

C inlet - total

Outlet

C in crude gas
C in tar, oil
C in the organic mass of phenol water
C in the unburnt residue
(C in fly-coal dust)
C outlet - total

4.1.2 Balance of hydrogen

Inlet

H in the moisture of coal
H in the combustible matter of coal
H in gasification steam
H in jacket feed water
H inlet - total

Outlet

H in crude gas
H in phenol water
H in tar, oil
(H in the unburnt residue)
(H in fly-coal dust)
(H in the organic mass of phenol water)
H outlet - total

4.1.3 Balance of oxygen

Inlet

O in the moisture of coal
O in the combustible matter of coal
O in gasification oxygen
O in gasification steam
O in jacket feed water
O inlet - total

Outlet

O in crude gas
O in phenol water
O in ash
(O in tar, oil)
(O in the organic mass of phenol water)
(O in fly-coal dust)

O outlet - total

The values given in parentheses are very low in the case of a steady process and owing to this they can be neglected.

4.2 Heat balance

For its calculation considered are:

Inlet: coal (latent and sensible heat)
gasifying agent
jacket feed water
feed water for WHB
cooling water into the after cooler

Outlet: crude gas (latent and sensible heat)
steam in crude gas
steam generated in the LP steam boiler
tar, oil (latent and sensible heat)
phenol water (latent and sensible heat)
ash (latent and sensible heat)
water from the after cooler

4.3 Values obtained from the balances

$$\text{Carbon conversion \%} = \frac{C_{gas}}{C_{coal}} \cdot 100$$

or

$$\text{Carbon conversion \%} = \frac{C_{gas}+C_{tar}+C_{oil}+C_{fw}}{C_{coal}} \cdot 100$$

where C_{gas}, C_{tar}, C_{oil}, C_{fw} ...... the amount of carbon in gas, tar, oil, and phenol water, produced from 1 kg of coal $kg.kg^{-1}$

C_{coal} ...... the amount of carbon in 1 kg of coal $kg.kg^{-1}$

$$\text{Gasification efficiency \%} = \frac{\text{CV of gas} \cdot \text{yield of gas}}{\text{CV of coal}} \cdot 100$$

$$\text{Thermal efficiency \%} = \frac{\text{Thermal contents of products}}{\text{Thermal contents of substances entering the process}} \cdot 100$$

4.4 Determination of the degree of steam decomposition

Water or steam into the gasification installation is brought by

- coal		
a) water from the moisture of coal	H_2O	1a
b) water produced in the process of carbonization during gasification	H_2O	1b
- jacket feed water	H_2O	2
- gasification steam	H_2O	3
- injection of phenol water into WHB	H_2O	4

Water or steam from the gasification installation is removed as:

- phenol water from WHB	H_2O	5
- phenol water from the after cooler	H_2O	6
- moisture of crude gas leaving the installation (its quantity is determined by the dew-point of gas at a given temperature and pressure).	H_2O	7

For the determination of the degree of steam decomposition considered are:

- steam given in the items H_2O 1a , H_2O 1b , H_2O 2 transfers to gas without any changes
- steam given in the item H_2O 4 , in the steady state it is irrelevant for the balance
- items H_2O 3 , H_2O 5 , H_2O 6 are determined from the measurements given in chapter 2
- item H_2O 7 is determined from the quantity of produced gas and from its pressure and temperature also on the basis of the data given in chapter 2.

The degree of gasification steam decomposition expressed in % is determined from the relation:

$$\% \text{ of decomposition} = \frac{H_2O\ 3 - (H_2O\ 5\text{-}7 - H_2O\ 1a\text{-}2)\ .\ 100}{H_2O\ 3}$$

where $H_2O\ 5\text{-}7 = H_2O\ 5 + H_2O\ 6 + H_2O\ 7$

$H_2O\ 1a\text{-}2 = H_2O\ 1a + H_2O\ 1b + H_2O\ 2$

5. The goal of the project and the programme of gasification tests

The goal of the project is to verify the gasification property of bituminous coals produced in the region Singareni collieries Andhra Pradesh Godavary mine as well as of coal from the Wardha Valley. Concerned are non-caking bituminous coals with the moisture content in the original state

$W_t^r = 5 - 10$ wt.%

and with the ash content in the original state

$A^r = 23 - 25$ wt.%, i.e. approximately A^d 24 - 28 wt.%

The programme of gasification tests involves:

1. Gasification with air and steam
2. Gasification with oxygen and steam.

Gasification with air and steam represents the first experimental section (considered is pressure of 1.5 MPa) lasting 24 hours in the case of all tests.

In gasifying with oxygen and steam the optimalization of the gasification ratio and the final gasification pressure of 2.4 MPa are always under consideration. Presupposed is the gasification of coal of 6 - 25 mm grain size which, according to hitherto practical experience, should be optimum. According to the programme the gasification tests should be performed during the period of June 1984 - September 1985. The tests will be followed by the preparation of a report in the period October - November 1985. The time schedule of the tests is evident from the following survey (see pages 16,17).

The programme suggested corresponds to the possibilities of the experimental working place of the RRL Hyderabad and according to time necessary for the preparation of pilot-plant tests, their performance and evaluation and for the preparation of reports also from the standpoint of financial claims to the tests it represents the optimum utilization of time and financial means intended for the programme of coal gasification.

6. Training programme

The following programme of training the respective workers of the RRL Hyderabad in Czechoslovakia was discussed and recommended:

- Mr K. Seshagiri Rao
- Mr T.S.R. Anjaneyulu

The operation of a large gasifier, measurements and collection of data carried out in a full-scale installation, evaluation of full-scale gasification tests, machinery of a pressure gasifier.

Palivový kombinát 25. únor, Vřesová
(Integrated coal mining and processing works)   2 weeks

Programme of gasi

Test no.	Date	Coal	Gasifying agent
1.	June 1984	Godavary I grain 6 - 25 mm	steam-air steam-oxygen
2.	September 1984	Godavary I	steam-air steam-oxygen
3.	December 1984	Godavary II grain 6-25 mm	steam-air steam-oxygen
4.	February 1985	Godavary III grain 6-25 mm	steam-air steam-oxygen

ification tests

Pressure (MPa)		Purpose of the test
1.5	1 day	1. optimalization of the gasification ratio 2. verification of the effect of pressure on the gasification process
1.5	2-3 days	
2.0	2-3 days	
2.4	2-3 days	
1.5	1 day	verification of the particle size effect grain 6 - 25 mm 10 - 50 mm 3 - 25 mm
2.4	7-9 days	
1.5	1 day	1. optimalization of the gasification ratio 2. verification of a new coal feed
2.4	7-9 days	
1.5	1 day	1. optimalization of the gasification ratio 2. verification of a new coal feed
2.4	7-9 days	

Continuation

Programme of gas

Test no.	Date	Coal	Gasifying agent
5.	June 1985	Godavary IV	steam-air
6.	September 1985	Wardha Valley grain 6-25 mm	steam-air steam-oxygen

ification tests

Pressure (MPa)		Purpose of the test
1.5 2.4	1 day 7-9 days	1. optimalization of the gasification ratio 2. verification of a new coal feed
1.5 2.4	1 day 7-9 days	1. optimalization of the gasification ratio 2. verification of a new coal feed

Ústav pro výzkum a využití paliv, Praha-Běchovice
(Fuel Research Institute) 1 week

Výzkumný ústav potravinářské
a chladící techniky, Hradec Králové
(Research institute of food and cooling
technique) 1 week

October - November 1984

Mr K.V.R.S. Murty
Mr S.N. Reddy

The operation of a large gasifier, measurements and collection of data carried out in a full-scale installation, evaluation of full-scale gasification tests, machinery of a pressure gasifier.

Palivový kombinát 25. únor, Vřesová
(Integrated coal mining and processing works) 2 weeks

Ústav pro výzkum a využití paliv, Praha-Běchovice
(Fuel Research Institute) 1 week

Výzkumný ústav potravinářské
a chladící techniky, Hradec Králové
(Research institute of food and cooling technique) 1 week

February - May 1985

7. Lectures

For the consultation held in the RRL, Hyderabad, the following four lectures were prepared:

Lecture I. Importance of coal quality to fixed bed pressure gasification. The influence of pressure on gasification. Gasifying agent, its composition and temperature

Lecture II. Concept of pressure gas plants in Czechoslovakia and development of machinery

Lecture III. Prospects for the development of coal gasification

Lecture IV. Crude gas purification, conversion, cracking of tar vapours and conversion to methane

However, with regard to time shortage, only the first two lectures were read. On the basis of these lectures the effects of the water content, of the content and composition of ash matters as well as the effect of the grain size of coal upon the gasification process were thoroughly discussed. Considerable attention was paid to the determination of the reactivity of coal towards CO_2 under atmospheric pressure, in particular, the methods of measuring and evaluating the data obtained as well as the methodology of determining the sintering temperature of ash were dealt with in detail. As to the technology of gasification, the importance of the composition and temperature of the gasifying agent was also discussed.

In the case of the second lecture besides the experience obtained from the full-scale operation the overall solutions to producing plants were also discussed with regard to the final processing of the produced crude gas and to the preparation of the raw material, of the gasifying agent, and of the heat and electric energy. Particular attention was given to the development of the main element of the machinery, i.e. the pressure gasifier for fixed bed gasification.

The lectures are presented in the Appendices.

Appendices

Lecture I.	Importance of coal quality to fixed bed pressure gasification. The influence of pressure on gasification. Gasifying agent, its composition and temperature
Lecture II.	Concept of pressure gas plants in Czechoslovakia and development of machinery
Lecture III.	Prospects for the development of coal gasification
Lecture IV.	Crude gas purification, conversion, cracking of tar vapours and conversion to methane

Lecture I.

1. Importance of coal quality to fixed-bed pressure gasification

The nature of a coal processed determines by itself the operating conditions, affects the specific consumptions of basic raw materials as well as the yield and composition of gas. It is desirable that the decisive parameters of coal intended for gasification should fluctuate within a small range and should not exceed the limit of the gasification process. The basic characteristics decisive for the choice of both the construction and the pressure gasification technology are as follows:

Content and composition of the combustible matter,
Water content,
Content and composition of ash matters,
Grain size of coal.

1.1 Combustible matter

The composition of the combustible matter and the ratio between the volatile matter and fixed carbon are determined by the geologic age of the fuel. In processing the fuels of different geologic age, the distinct specific consumptions of the combustible matter are attained, distinct also are the yields and the composition of produced gas. For example, according to literary references, in purified gas (after CO_2 scrubbing) the CH_4 content is 4.2 vol. % and 17.8 vol. % in gasifying the anthracite and in gasifying the lignite respectively. Similar findings ensued from the full-scale measurements carried out in Czechoslovakia.

On the basis of experience obtained up to now we may generally state that the nature of the combustible matter of coal cannot practically make its use for gasification impossible. In concrete cases (e.g. caking coals), the application of a suitable design concept as well as the utilization of the pressure machinery equipment guaranteeing a uniform course of the gasification process is important.

1.2 Water

In practice a high water content in run-of-mine coal is reduced to a technically and economically acceptable level before gasification.

The effect of the water content in lignite on the gasification process was dealt with in many studies in Czechoslovakia. The tests with coal with the water content W_t^r 13.5-38 wt. % carried out at the pressure gas plant Ústí nad Labem proved that when the water content increased by 1 wt. %, the specific consumption of oxygen increased on the average by 0.6 wt. %. The crude gas composition changes only slightly with the increasing content of water in coal; the carbon dioxide and hydrogen contents slightly increase whereas at the same time the carbon monoxide portion decreases. Of course, in deeper drying the charge, the portion of produced phenol water also decreases.

Nevertheless, at present in the gas plant Vřesová the fuel with the water content higher than it was presupposed is gasified - the annual average attains approximately 30-32 wt. %. The tests with screened not dried coal containing about 40 wt. % of water were also successful.

1.3 Ash matters

Inorganic substances - ash matters - in coal pass through a number of physical and chemical changes during the gasification process. With regard to difficulties in isolating and identifying ash matters, the value derived - ash is used in the technical practice. For a preliminary evaluation of the fuel suitability for gasification, the absolute amount of ash, its composition and its fusion temperature are important.

The composition of ash and its fusibility are significant for the formation and character of slag during gasification. The ash with a higher softening point is more advantageous from the technical and economic standpoint.

The measurements and practical operational experience explicitly confirmed the higher ash content unfavourable effect on the gasification process. The evaluation of the two years' operation of the gas plant Ústí nad Labem shows that in the case of lignite with the ash content A^d (6-22 wt. %), the specific consumption of oxygen increases by 1.9 % when the ash content is increased by 1 wt. %. As to the specific consumption of combustible matter, its increase by 1 wt. % was found in the ash content increase by 1 wt. %. The data ascertained are rather of an informative character - they are valid only for the fuel evaluated and for the given technological régime. The upper limits of the ash content in coal for the fixed-bed pressure gasification are also dependent on the ash composition and on other properties of coal, they range from A^d 25-30 wt. %.

1.4 Grain size of coal

According to our experience the grain size of coal and its resistance to disintegration influences mainly the aerodynamic conditions in the gasifier bed and thus also the mass and heat transmissions during the gasification process.

With regard to charge granulation, the conditions in pressure gasifiers are more favourable than those in pressureless installations. In spite of this fact, in connection with an effort to achieve a higher output of the plant, the original range specified for lignites 3 to 25 mm is narrowed and the grain sizes, e.g. 5-25 mm, 7-30 mm, 10-40 mm or 20-60 mm are recommended. The most harmful is the high portion of undersize. The gasification of charges of 0-25 mm, 3-25 mm, and 10-25 mm in our plants showed the following:

In gasifying a well screened coal the process is stable, the temperatures in the gasifier are steady and the CO_2 content fluctuates within a small range. The fuel enables to achieve high outputs of the gasifier. When fuel with a higher portion of fine grains is gasified, the process is unstable, the gas temperature varies and at the same time increases. The CO_2 portion in crude gas increases, the same concerns the unburnt residue portion in ash as well as the specific consumption of oxygen. The operation with unscreened coal cannot be permanently kept even at a low output, also a considerable entrainment of dust is found. During the repeated tests with unscreened coal the gasifier was operational for 16-48 hours as a maximum and then it was necessary to put it out of operation.

Current analyses of coal are sufficient for basic technological and thermodynamic evaluations of the gasification process but they do not enable to evaluate the kinetics of the processes in course. Owing to this, the measurements of coal reactivity are carried out on a laboratory scale and provide further valuable data for evaluating the kinetics of the processes in course.

The second group of problems dealt with at our institute covered the determination of the fusible properties of ashes. We made use of the well-known fact that during the ash heating already before attaining the standardized softening temperature (t_A), the significant structural changes take place and may cause the formation of solid agglomerates.

1.5 Determination of reactivity

Of potential methods we selected for our case the fuel reactivity to carbon dioxide under atmospheric pressure. For the given purpose we proposed and built a simple laboratory apparatus (Figure 1), based on observing the composition of reactive gaseous products at a selected flow of carbon dioxide. In order to analyze the formed gases (approximately a CO_2 + CO binary mixture), we used a thermal-conductivity detector. With the aim to improve the reproducibility of the results obtained by using this method, we used the samples of semi-coke prepared at a temperature of 900 °C, i.e. with a considerably reduced content of hydrogen.

Having regard to the fact that our goal was to develop a comparable method, during the measurements the following constant conditions should have been adhered to:

- The weight of the charge and its grain size,
- The size of the employed reactor,
- The flow of the gasifying agent,
- A method of sample preparation,
- A temperature of measurement.

The velocities of carbon degradation are calculated from the carbon dioxide flow and from the immediate concentration of carbon monoxide in produced gas. Of these a set of values of the degree of carbon conversion for the given interval is obtained.

By means of interpolation the reaction times for 50 % and 90 % conversions ($\tau_{0.5}$ and $\tau_{0.9}$) are calculated.

As a parameter characterizing the semi-coke behaviour during the initial stages of reaction, the degree of attaining the chemical equilibrium X_{CO} at the beginning of the measurement was selected and defined

$$X_{CO} = \frac{(C)_o}{(C)_R}$$

where $(C)_o$ is the extrapolated CO value in the reaction gas at the beginning of the reaction,

$(C)_R$ is the equilibrium CO concentration for the given reaction at a temperature of measurement.

The accuracy of the determination of the coal parameters obtained from measuring the reactivity is as follows:

	x_{CO}	$\tau_{0.5}$ [min]	$\tau_{0.9}$ [min]
Δ % rel.	± 5	± 6	± 4

The typical results of measuring the reactivity are presented in the following Table.

Sample	Type of coal	$\tau_{0.5}$ [min]	$\tau_{0.9}$ [min]	x_{CO} [%]
1.	Low rank lignite	12.7	25.2	64.2
2.	Xylitic lignite	13.2	29.8	62.0
3.	Lignite	19.6	43.3	61.9
4.	Lignite	16.3	42.5	48.7
5.	Lignite	27.5	58.4	33.1
6.	Subbituminous non-caking	39.7	90.5	27.7
7.	Bituminous	-	-	7.2
8.	High rank bituminous	-	-	3.0

By using the given method intended mainly for lignites, many samples were already investigated. This method can also be used for low-reactive bituminous coals.

1.6 Determination of the sintering temperature of ash

In order to study the ash fusibility, the Fuel Research Institute, Prague suggested and verified a simple, rapid method based on observing the structural changes of ash taking place before attaining the softening temperature t_A. This value - - sintering temperature is denoted t_S.

The method according to the Czechoslovak patent is based on observing the changes taking place during sintering in the pneumatic resistance of a loose layer of the powdered sample of ash. First, the layer resistance in the measuring gas passage increases with the increasing temperature. In the moment of sintering, a free space is formed along the walls of the measuring tube as a consequence of the layer contraction and owing to this the overall resistance of the layer decreases. In continuous recording the flow in dependence on temperature contingently on time the extreme value during the above changes is recorded (Figure 4); it can be easily read and is well reproducible. The diagram of the measuring apparatus is shown in Figure 5 .

The results of measurements demonstrated a good reproducibility of this method, repeated measurements showed a dispersion variance ± 1.4 % to ± 1.7 %.

We also compared the t_s value with the standardized ones of ash fusibility.

The results are presented in the following Table.

Fuel	t_s	t_A	t_B	t_C	$\Delta (t_A - t_s)$
	°C				
Xylitic lignite	918	1095	1175	1205	177
Lignite	892	1100	1150	1155	208
	1043	1120	1240	1275	77
	1000	1155	1285	1300	155
	1057	1165	1290	1310	108
Bituminous coal	932	1065	1320	1340	133
	1078	1205	>1500	>1500	127
	920	1215	1485	1490	295

2. The influence of pressure on gasification

The gasifying pressure in fixed-bed gasification represents a basic parameter and owing to this both practical and theoretical studies in this field received great attention. The practical full-scale experience is in good agreement with the theoretical assumptions. The methane and carbon dioxide contents in gas increase with the increasing pressure, at the same time the portions of hydrogen and carbon monoxide decrease. In gasifying lignite of the composition (wt. %): water 22.0, ash 5.5, combustible matter 72.5, the crude gas of the following composition (vol. %) was obtained:

Pressure MPa	0.1	0.38	0.92	1.50	2.10
CO_2	26.3	28.8	33.0	33.4	33.7
C_nH_m	0.4	0.4	0.6	0.6	0.6
O_2	0.2	0.3	0.3	0.2	0.1
CO	24.4	18.8	14.6	14.4	14.0
H_2	44.9	42.0	37.3	36.4	35.4
CH_4	2.9	8.2	12.2	13.5	15.0
N_2	0.9	1.5	2.0	1.5	1.2
Gross calorific value $MJ . m^{-3}$	10.3	11.3	11.7	12.0	12.5

With respect to the fact that with increasing pressure the thermal content of gas increases, the coal gasification under the highest possible pressure is advantageous. However, in the full-scale installations successively constructed since the forties, the operational pressure ranging between 2.0 and 3.0 MPa has been stabilized with regard to the optimum increase in methane in the produced gas, as well as with regard to the requirements for the machinery and investment costs connected with its construction.

This value was also applied in Czechoslovak pressure gas plants and the constructed town-gas network uses the pressure of about 2.0 MPa.

However, in the FRG the RUHR 100 technology is at present verified with satisfactory results in order to gasify coal at a pressure up to 10.0 MPa in a unit of 1.5 m diameter. The aim of this is to achieve a further increase in the specific output of a gasifying unit as well as to increase the methane content in gas. In this unit the specific output 9200 m^3 crude gas $.m^{-2}.h^{-1}$ was already attained, the methane content in gas increased from 9 to 16 vol. % when the pressure was risen from 2.5 MPa to 9.0 MPa.

3. Gasifying agent, its composition and temperature

At initial stages of the development and operation of pressure gas plants the technical oxygen with the minimum nitrogen content was required and coal was gasified with highly overheated steam of a temperature up to 500 °C which supplied the gasifier with more heat and enabled to save oxygen.

Later, however, when bituminous coals with lower contents of volatile portions were gasified under current operational conditions, the preparation of town gas of the required gross calorific value above 16.7 $MJ.m^{-3}$ after purification was not successful and thus the initial aims lost their importance. The full-scale tests demonstrated that at a lower temperature of the gasifying steam the gasifying ratio, the steam consumption, and the production of waste phenol waters might also be reduced. Considered was also gasification with lower-concentrated oxygen at its minimum production costs.

At present in our gas plants steam of a temperature ranging from 350 to 400 °C is used, the oxygen concentration attains 95 vol. %. However, the properties of gas after its purification are permanently modified by adding natural gas and nitrogen in order to achieve the quality of town gas.

Another important factor for the gasification process is the gasifying ratio, i.e. the ratio of steam (kg H_2O) to oxygen (m^3 O_2).

A higher gasifying ratio results in cooling the reaction zones, which supports the carbon dioxide formation at the expense of carbon monoxide as well as the increase of the hydrogen portion in gas. The steam decomposition also worsens and thus phenol waters are produced in larger quantities. From the economic point of view the lowest possible gasifying ratio is thus advantageous, of course, if ash fusibility permits.

The dependence of the crude gas composition on the gasifying ratio, as ascertained in the operation of the pressure gas plant Ústí nad Labem, is proved by the graph in Figure 6.

The composition of gas may be changed, besides the change in the gasifying ratio, also by the admixture of nitrogen. At the same time when the oxygen concentration decreases from 100 % to 60 %, the net calorific value of crude gas decreases by approximately 16 %, below 60 % of oxygen the decrease is quicker. This is caused by increasing the nitrogen portion in gas at the expense of methane and of other components. The application of gasification with low-concentrated oxygen, thus mainly with air, is taken into consideration in association with the production of gas for power purposes.

A partial replacement of steam with carbon dioxide was verified on an experimental scale to produce synthesis gases which, obviously mainly due to operational difficulties caused by corrosion, was not applied in practice.

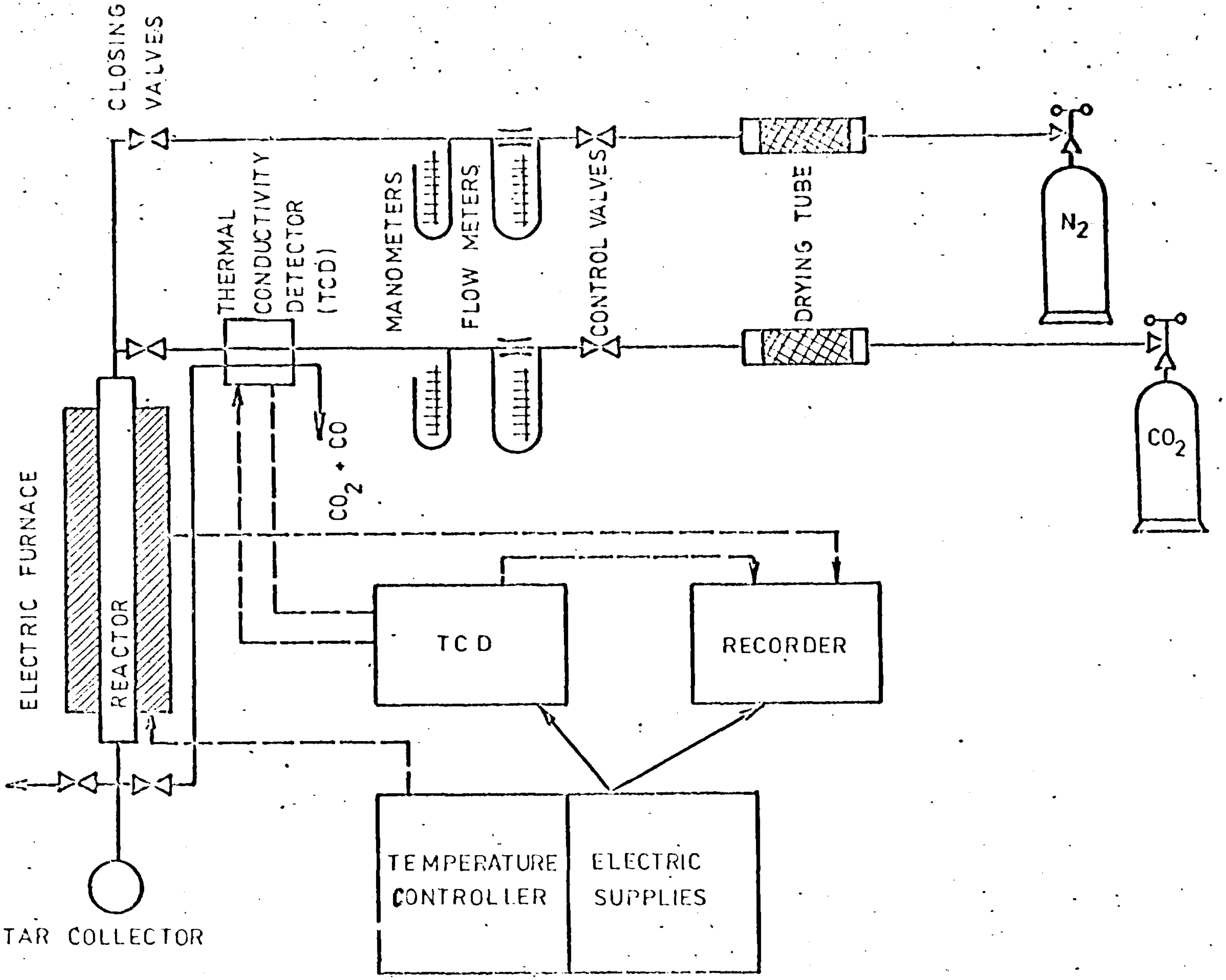

FIGURE 1. APPARATUS FOR THE DETERMINATION OF REACTIVITY

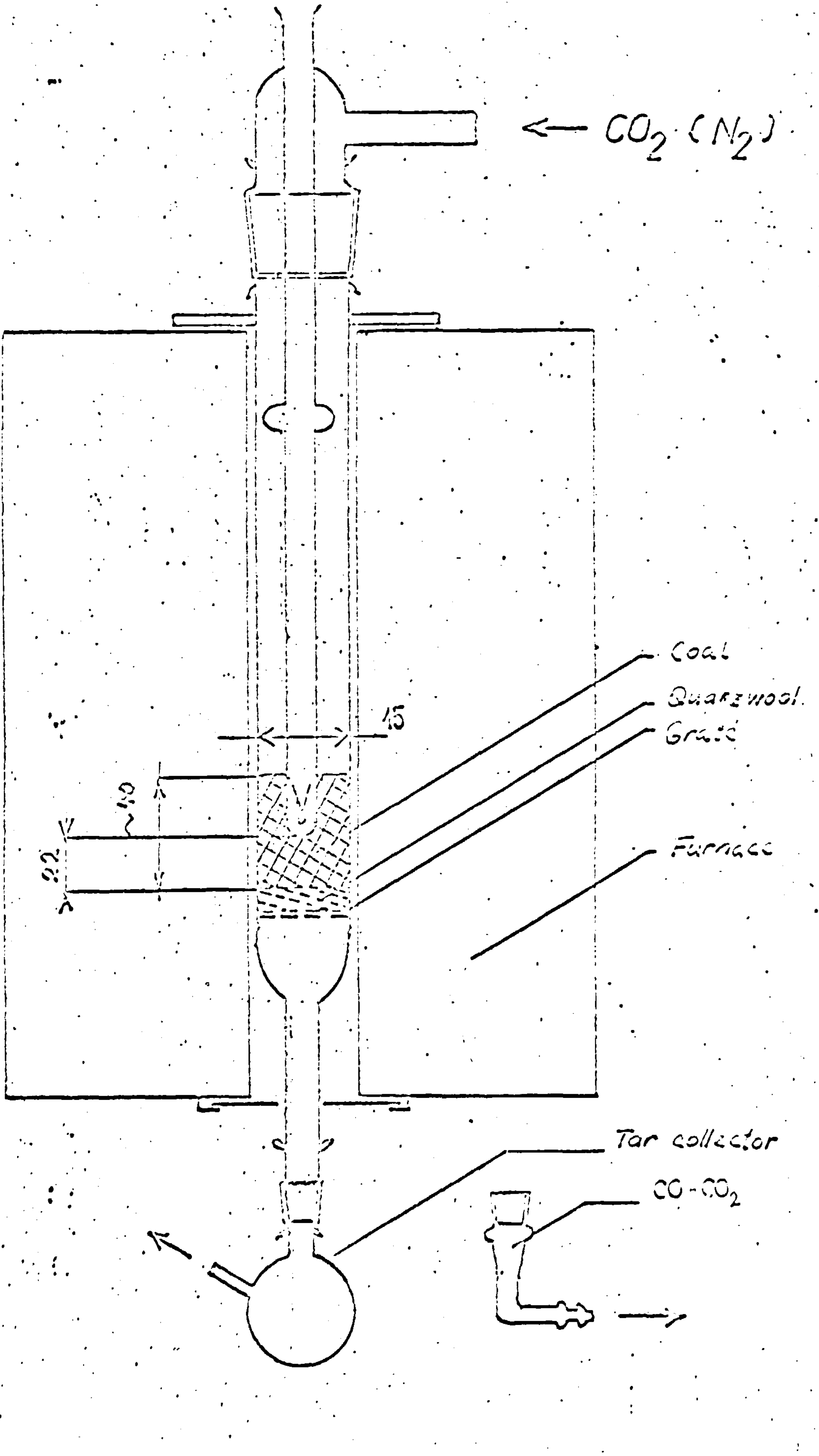

Fig. 2. Reactor

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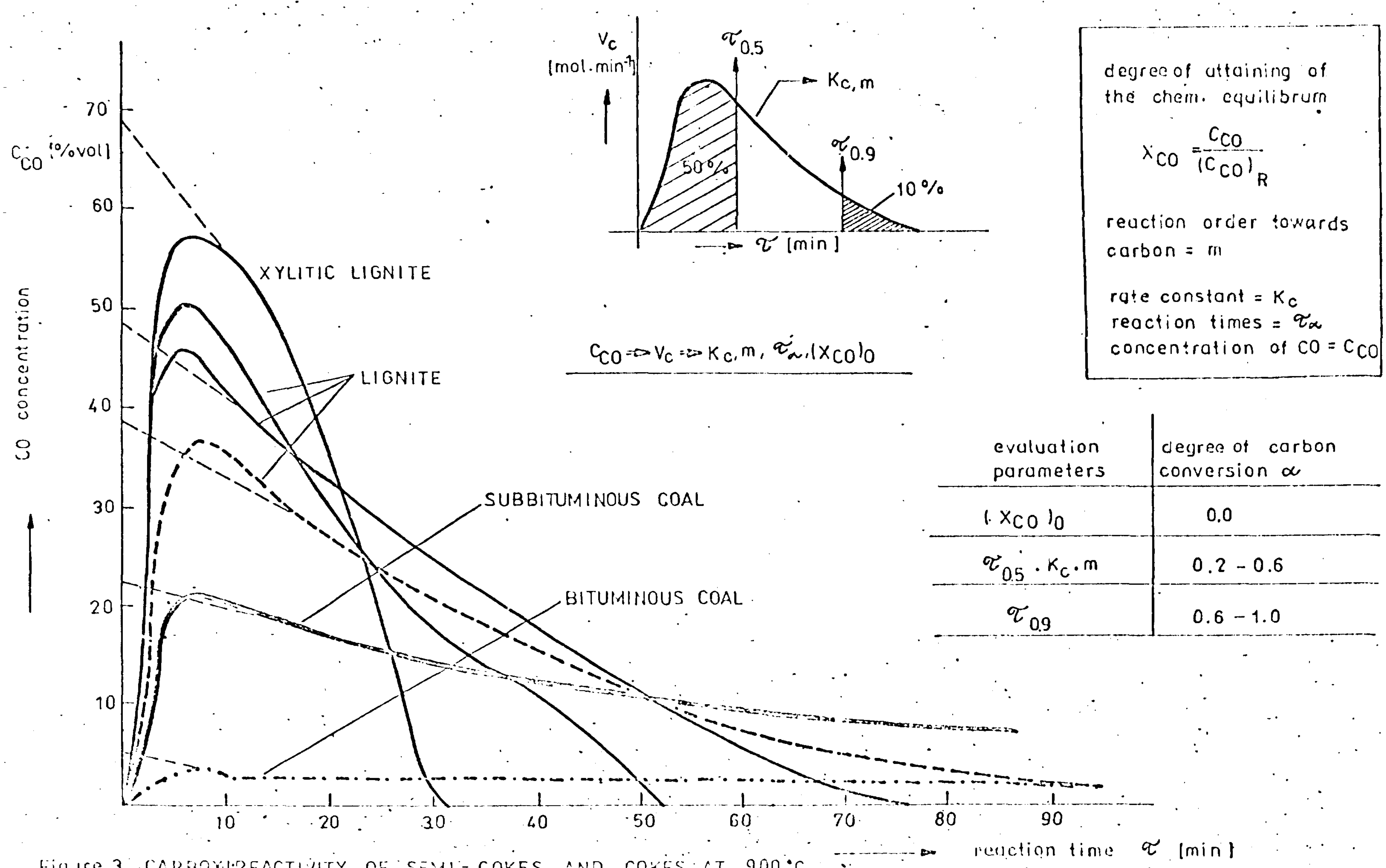


Figure 3. CARBOXYREACTIVITY OF SEMI-COKES AND COKES AT 900 °C

$$C_{CO} \Rightarrow V_c \Rightarrow K_c, m, \tau_\alpha, (X_{CO})_0$$

degree of attaining of the chem. equilibrum

$$X_{CO} = \frac{C_{CO}}{(C_{CO})_R}$$

reaction order towards carbon = m

rate constant = K_c

reaction times = τ_α

concentration of CO = C_{CO}

evaluation parameters	degree of carbon conversion α
$(X_{CO})_0$	0.0
$\tau_{0.5} \cdot K_c \cdot m$	0.2 - 0.6
$\tau_{0.9}$	0.6 - 1.0

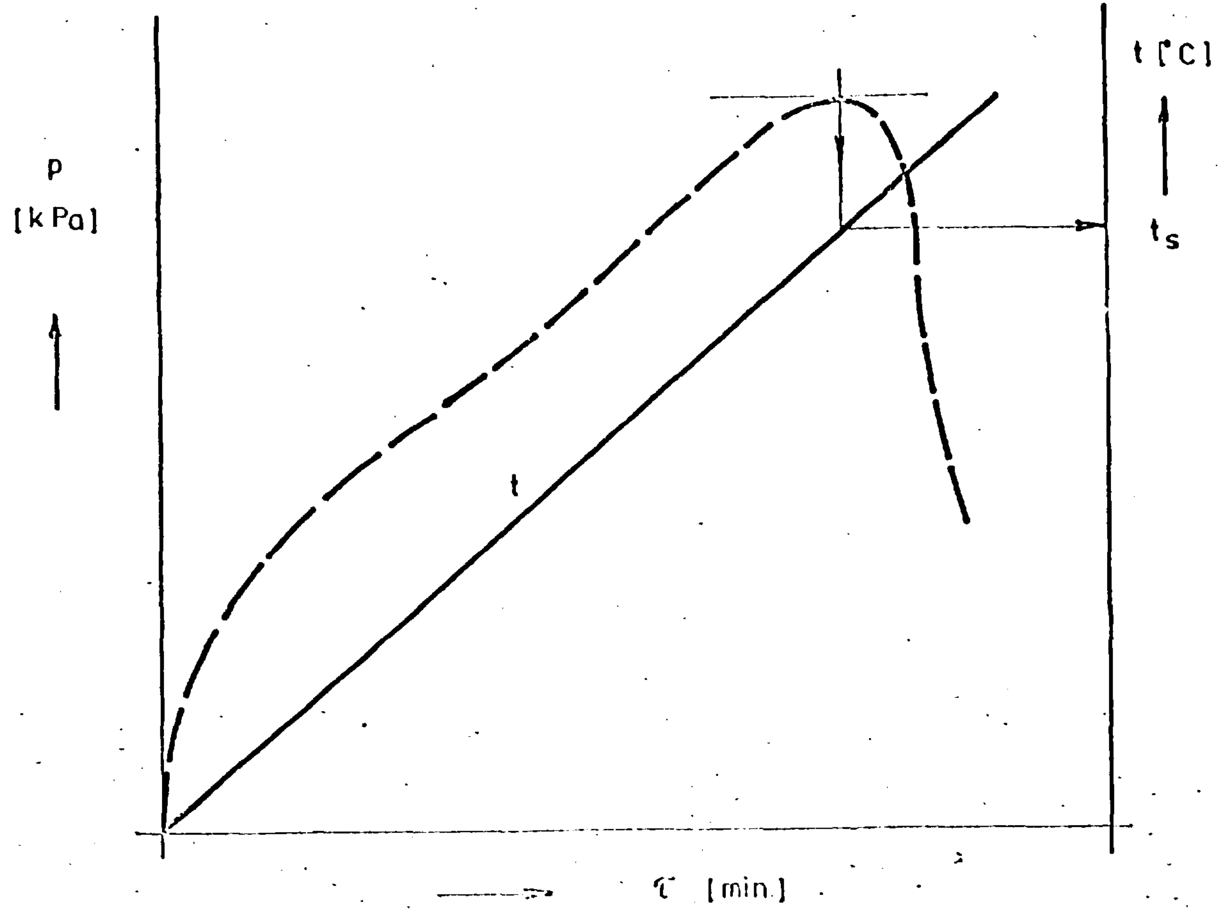
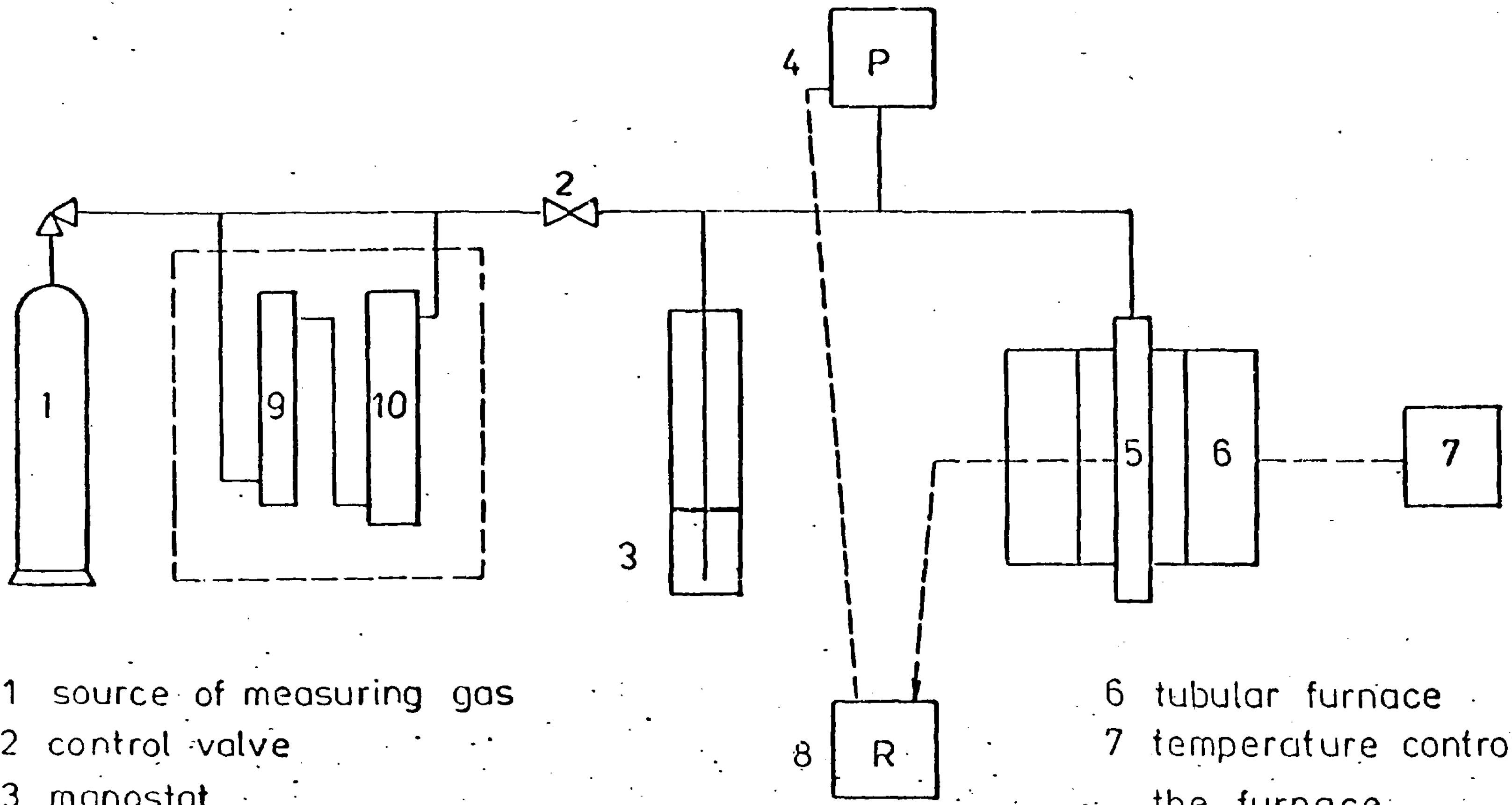


FIGURE 4. RECORD OF SINTERING TEMPERATURE MEASUREMENT

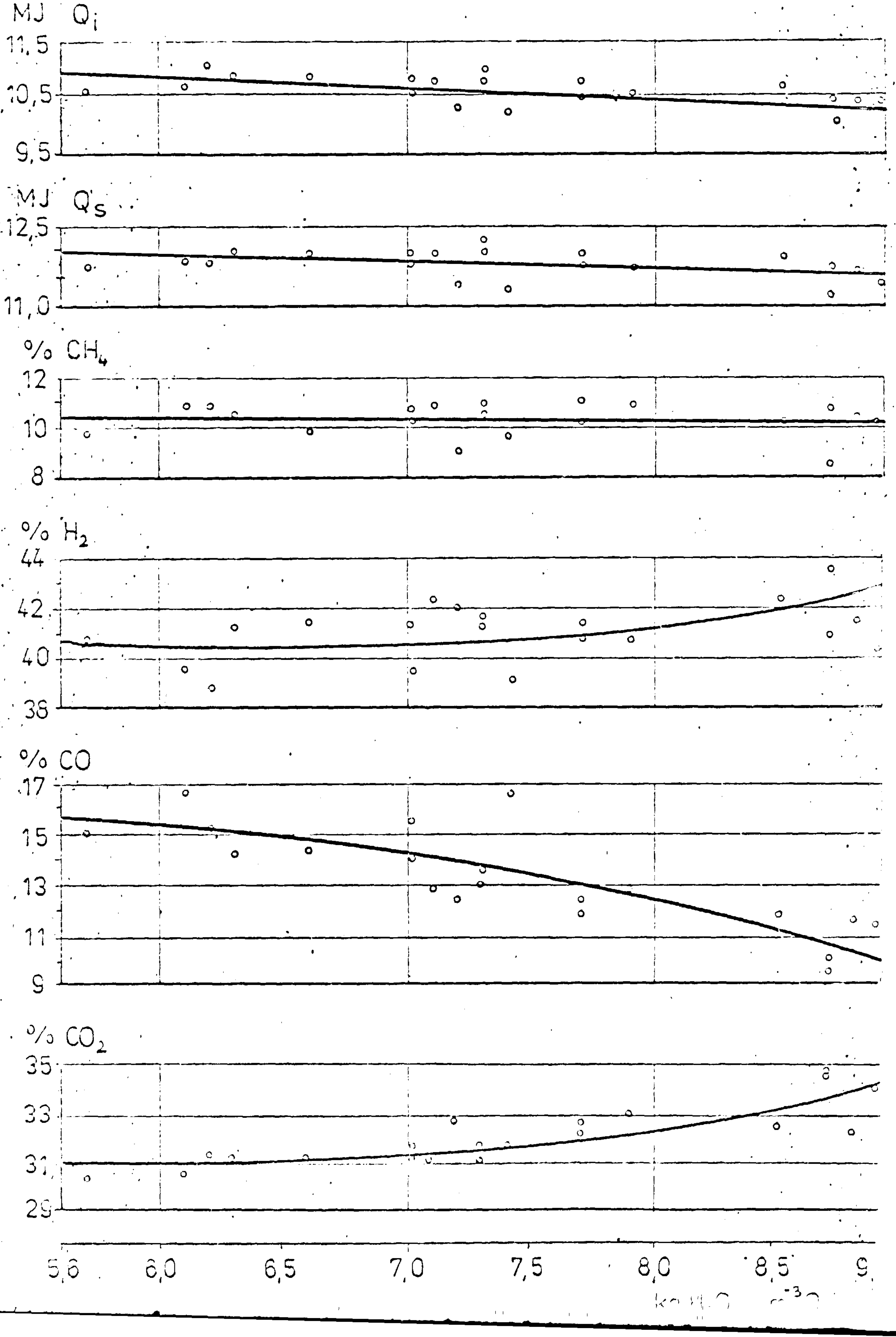
FIGURE 5. APPARATUS FOR MEASURING THE SINTERING TEMPERATURE



1 source of measuring gas
2 control valve
3 manostat
4 manometric transmitter
5 measuring tube

6 tubular furnace
7 temperature controler of the furnace
8 two-pen or X-Y recorder for recording the values of temperature and presure
9. flowmetr
10 drying

FIGURE 6. DEPENDENCE OF GAS COMPOSITION ON GASIFICATION RATIO



Lecture II.

Concept of pressure gas plants in Czechoslovakia and development of machinery

The reserves of lignite and the requirement for modernizing the town gas production in Czechoslovakia led in the fifties to make a decision on a widening and further constructing of pressure gas plants.

In this country the first pressure gas plant was constructed already in 1943 near Most as a part of the chemical works processing lignite. Another two pressure gas plants in Ústí nad Labem and in Vřesová were put into operation in 1961 and 1969 respectively.

1. The pressure gas plant in Most

The three initial gasifiers were stepwise completed in the fifties with further thirteen gasifiers built by the firm "Škoda ZVÚ Hradec Králové". The gas production in this plant covers only gasification of coal and gas purification by methanol scrubbing. The supplies of electric power, oxygen and of steam as well as the preparation of coal and treatment of waste waters are carried out in the joint installations of the plant. The pure gas produced is enriched with natural gas and with further gases from the refinery section of the integrated works and the nitrogen admixture permits to modify the properties of gas in such a way to achieve the values required by the respective standard. Of the initial sixteen gasifiers at present only twelve are in operation and with regard to their age the plant operation is gradually limited. Consequently, of the maximum productions exceeding 700 mil m^3 of town gas per year, approximately 400 mil m^3 are attained at present.

Gasified is not dried lignite with the water content lower than 30 wt. %.

2. The pressure gas plant Ústí nad Labem

This pressure gas plant was built as a complex self-sufficient as to energy to process coal produced in the neighbouring surface mine.

The integrated works are divided into a part of the gas plant (coal preparation, production and purification of gas), power plant (steam production, electric power and oxygen production) and water economy part (supplying water and purification of waste waters). The mentioned technology parts are tightly connected to each other and their management calls for a perfect coordination. From the raw coal supplied, about 70 % is gasified (after preliminary drying in this plant). The generator room has 14 ŠKODA pressure gasifiers, the power plant has 4 boilers with a power output of 75 $t.h^{-1}$ of steam and 9.5 MPa and 535 °C and two turbo-sets, 12 MW each. Oxygen is produced in low-pressure separating apparatuses with a capacity of 5400 m^3 oxygen per hour. The oxygen compression is provided by turbocompressores. Crude gas is purified by washing in methanol on the Rectisol installation. Waste phenol waters are extracted by butyl acetate with complementary purification through biological processes. In the integrated works about 1 Mt of the mined lignite is processed every year, yielding more than 400 Mm^3 of town gas. For a basic technological flow sheet of the pressure gas plant see Fig. 1.

3. The pressure gas plant Vřesová

As to its concept, the largest Czechoslovak pressure gas plant is distinctively different from the preceding ones. It is represented by integrated fuel works producing the town gas, electric power and briquettes. The method of production and purification of gas and treatment of by-products is essentially the same as in the pressure gas plant Ústí. The designed capacity of the gas plant is of 1.3 Gm^3 of town gas a year, 26 ŠKODA pressure gasifiers are installed. The electric power plant has 5 dry-bottom pulverized-fuel fired boilers for steam at 13.9 MPa, total electric power output of installed turbines is of 220 MW, a major portion of the electric power is supplied into the network. The briquetting plant is able to produce as much as 1 Mt briquettes a year.

Parameters of the gasification process

For a review of technology parameters of the gasification process and characteristics of coal to be gasified in Czechoslovak pressure gas plants Ústí and Vřesová see Table 1.

In pressure gasifiers the fraction from 3 or 5 to 25 mm is usually gasified, however, there is also operation experience with a different grain-size (e.g. 8 to 50 mm or with the gasification of a narrow range of the grain-size and also with a broad range). The design characteristics of new gasifiers makes also possible the gasification of coals with higher contents of fine fractions, and experience was also gained in the practice with the operation of pressure gasifiers in the course of the gasification of coal containing up to 20 wt. % of screen undersizes 0 to 5 mm.

Coal need not be always dried before the gasification, which depends on the entire technology concept of the pressure gas plant. However, when the water content in coal is above 30 wt. %, then it is reasonable to use the preliminary drying.

Operation parameters of the gasification process, particularly the gasification pressure, are essentially determined in connection to further main technology parts of the pressure gas plant (oxygen plant and thermal power station) and long-distance distribution of town gas. In Czechoslovak pressure gas plants the pressure gasifiers are operated at a pressure of about 2.5 MPa, however in general, lower or possibly also higher pressures can also be chosen. Highly concentrated oxygen (94 to 96 vol. %) in a mixture with pre-heated steam is used as a gasifying agent. Temperature of oxygen from the oxygen plant is of about 100 °C and that of high-pressure steam is of 360 to 400 °C. Of course, it is also possible to use steam with temperatures above 400 °C. The oxygen - to - steam ratio in the gasifying agent is usually between 6 and 7 kg steam per 1 m^3 of oxygen.

The specific consumption of the gasified lignite is between 0.9 and 1.2 $kg.m^{-3}$ crude gas. The specific consumption of the combustible matter, which is a more objective indicator, is of 570 to 630 $kg.10^{-3}.m^{-3}$ of the produced crude gas. The consumption of the combustible matter is affected by the character of coal (content of tar, ash, reactivity, etc.) and by technology parameters of the gasification process.

The total energy efficiency of the pressure gas plant, which is defined as a ratio between the sum of useful chemical heats of products (gas, tars and oils) and sum of energies entering into the processes, depends on a number of factors. During the lignite gasification it is possible to achieve as high efficiency as 59 to 64 %, depending on the coal quality. This result achieved during the application of the oxidizing gasification and use of lignite of inferior quality makes the pressure gasification efficient for the gas production even at present. The balance of the town gas production in an energetically self-sufficient pressure gas plant (only one main product is represented by town gas, electric power and steam are produced only for the consumption in the enterprise) is presented in Table 2.

Development of pressure gasifiers in Czechoslovakia

On the basis of the research and development, basic data were obtained for new enterprises in 1959 to 1968 for design works and production of powerful pressure gasifiers with an inside diameter of the shaft of 2.76 m. The gasifiers for the second pressure gas plant in Ústí were also characterized by a side ash disposal, however, their capacity was twice as higher as that of the gasifiers in the first pressure gas plant in Most, i.e. 9000 $m^3.hr^{-1}$ crude gas. The pressure gasifiers in Vřesová are of a new conception and with them as high capacity as 12 000 $m^3.hr^{-1}$ crude gas can be achieved during the gasification of lignite. The gasifiers have a three-step rotating grate with an adjusted surface, central and continuous ash disposal, automated coal charging, hydraulic handling of outlet ash from the ash lock hopper. The specific output of the gasifier is at a level of 2000 $m^3.hr^{-1}$ m^{-2} of the shaft. The pressure gasifier of the type "Vřesová" has a mass of 103 t (including the coal and ash lock hoppers) and the spacing between the upper and bottom flange of the body of the reactor itself is of 9050 mm. The construction height of the installation from the coal feeder above the coal lock hopper to the ash wash flue below the ash lock hopper is of 21 m. The pressure gasifier is equipped with a water jacket, where saturated high-pressure steam consumed for the gasification process is produced. A stepwise multislot grate serves for perfect distribution of the gasifying agent within the whole cross-section of the gasifier and thus, for a maximum use of the coal combustible matter for the gas production. A simple cylindrical piece in the upper part of the gasifier limits the gravitation separation of coal, during its supply into the gasifier.

A verifying operation has recently been started of the prototype of an innovated gasifier of 2.76 m diameter at the pressure gas plant in Ústí by means of which the gasifiers at the gas plants in Ústí and Vřesová should be stepwise replaced.

In the case of this new type the existing two-way coal feed hopper was replaced with a new one of a shape of frustum of pyramid with one outlet which would considerably limit the difficulties in coal transporting and would accelerate the filling of a coal hopper. In the upper part of the gasifier body the diameter of the gas off-take was enlarged to 700 mm and the cooling of gas was improved by modifying the phenol water injection. The pre-cooler is made as a one-shell type, extended in the bottom part. The bottom part of the gasifier internal shell is equipped with stainless material which should improve in this part resistance to weakening the shell during the operation. The constructional modifications of the grate were aimed at extending the service life of this highly heat-stressed part of the gasifier. New constructional solutions to closing cones of the ash lock hopper permit to shorten the construction height of the installation contingently to extend the gasifier body.

These improvements are presupposed to contribute mainly to shorten the time of repairs of the gasifier and to increase its utilization as to time up to 78 %.

The modifications in the upper part of the gasifier and in the pre-cooler should contribute to a more uniform operation of the installation and enable the increase in the output by approximately 15-20 % if coal of a suitable quality is used. Comparisons of the gasifiers of the type

Ústí, Vřesová and the innovated gasifier are evident from the respective Figures.

In addition to the innovated gasifier, at present a new mode of a continuous deashing of the gasifier is subject to investigation. In this case the ash lock hopper is replaced with a cylindrical vessel filled with water to which falls a continuously removed ash. In the hydromixture layer the ash is cooled and pressure is gradually reduced. The hydromixture is then permanently transferred to the ash channel by means of a turnstile. The installation was verified in a continuous operation for a period longer than one week. The results obtained were satisfactory. Final solution, in particular to difficulties caused by insufficient service life of materials used for the turnstile, is still needed.

Table 1 Parameters of the gasification process in pressure gas plants in Czechoslovakia

Parameters	Unit	Pressure gas plant			
		Vřesová		Ústí nad Labem	
		a	b	a	b
A. Inlet parameters					
1. Lignite: W_t^r	wt. %	45.00	30.8	39.6	24.2
A^r	wt. %	10.80	13.6	8.8	10.8
Gross calorific value: Q_s^r	$MJ.kg^{-1}$	12.16	15.3	-	18.84
2. Gasification agent:					
oxygen	vol. %	10.62			9.9
nitrogen	vol. %	1.18			0.6
steam	vol. %	88.17			89.4
3. Gasification steam temperature	°C	360			370
4. Gasification pressure	kPa	2550			2450
B. Outlet parameters					
Crude gas and town gas:		c	d	c	d
H_2	vol. %	40.6	48.48	39.3	53.6
CO	– " –	12.2	15.34	12.7	16.8
CH_4	– " –	11.2	19.86	10.9	16.9
CnHm	– " –	0.6	0.53	0.9	0.8

Table 1 continued

CO_2
N_2
O_2
$C_2+C_3+C_4$
Q_s
C. Specific consumptions and yields
Consumptions: coal
gasification agent
including steam
electric power
Yields: liquid hydrocarbons (including phenols)
D. Efficiencies: Overall energy efficiency of the process
Gasification efficiency (crude gas/gasified coal)

a = raw coal

b = predried (gasified) coal

c =

d =

	c	d	c	d
vol. %	33.7	12.98	32.2	4.9
- " -	1.5	2.04	3.0	5.6
- " -	0.2	0.2	0.3	0.5
- " -	-	-	0.7	0.9
$MJ.m^{-3}$	11.82	17.01	12.45	17.11
$kg.m^{-3}$	1.15	1.40	0.882	1.147
$m^3.m^{-3}$	1.57	1.92	1.364	1.773
$kg.m^{-3}$	1.12	1.37	0.981	1.275
$kWh.m^{-3}$	0.26	0.32	0.26	0.34
$kg.m^{-3}$	0.08	0.096	0.08	0.10
%	56.7		59.8	
%	67.2		74.9	

crude gas

town gas

Table 2 Balance of the town gas production in a pressure gas plant (1000 m^3 of gas considered as a basis)

Inlet:	
raw coal (total)	2 000 kg
natural gas (carburation)^x	80 m^3
raw water	10 m^3
air - power plant	2 900 m^3
oxygen plant	910 m^3
Outlet:	
a) Products	
town gas	1 000 m^3
tar	84 kg
crude benzol	6 kg
crude phenol	12 kg
sulphur	5 kg
ammonia water (10 %)	21 l
b) Wastes	
ash (slag)	208 kg
flue gases (power plant)	2 900 m^3
nitrogen (oxygen plant)	715 m^3
(phenol water)	(1 345 kg)
waste water (into the recipient)	5.3 m^3
waste gases (from gas purification)	304 m^3

x) adjustment of the gross calorific value of the pure gas to about 17 MJ.m^{-3}

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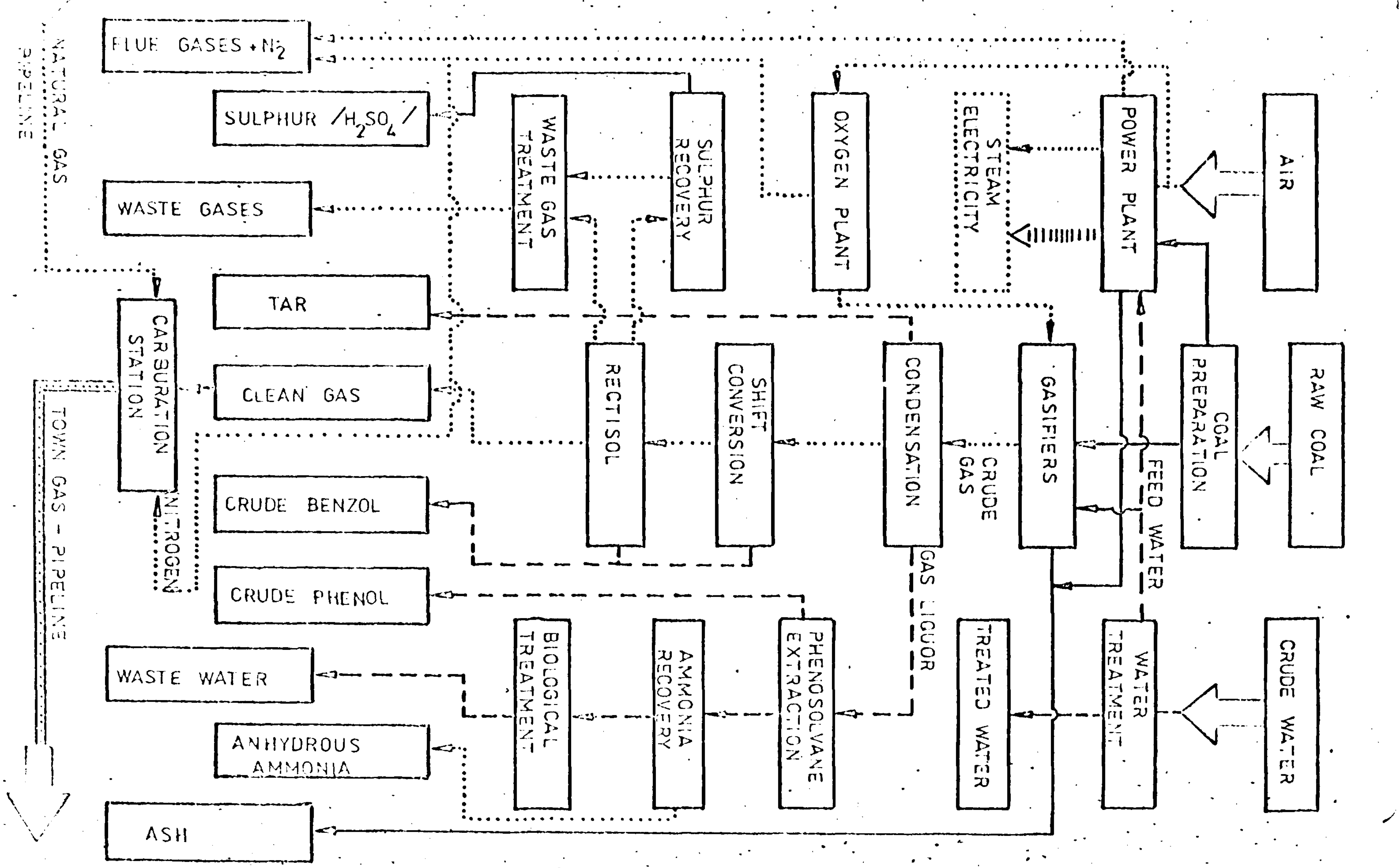
FLUE GASES + N_2
SULPHUR /H_2SO_4/
WASTE GASES
TAR
CLEAN GAS
CRUDE BENZOL
CRUDE PHENOL
WASTE WATER
ANHYDROUS AMMONIA
ASH
NATURAL GAS PIPELINE
CARBURATION STATION
NITROGEN
TOWN GAS - PIPELINE
WASTE GAS TREATMENT
SULPHUR RECOVERY
OXYGEN PLANT
STEAM ELECTRICITY
POWER PLANT
AIR
RECTISOL
SHIFT CONVERSION
CONDENSATION
CRUDE GAS
GASIFIERS
FEED WATER
COAL PREPARATION
RAW COAL
GAS LIQUOR
BIOLOGICAL TREATMENT
AMMONIA RECOVERY
PHENOSOLVANE EXTRACTION
TREATED WATER
WATER TREATMENT
CRUDE WATER

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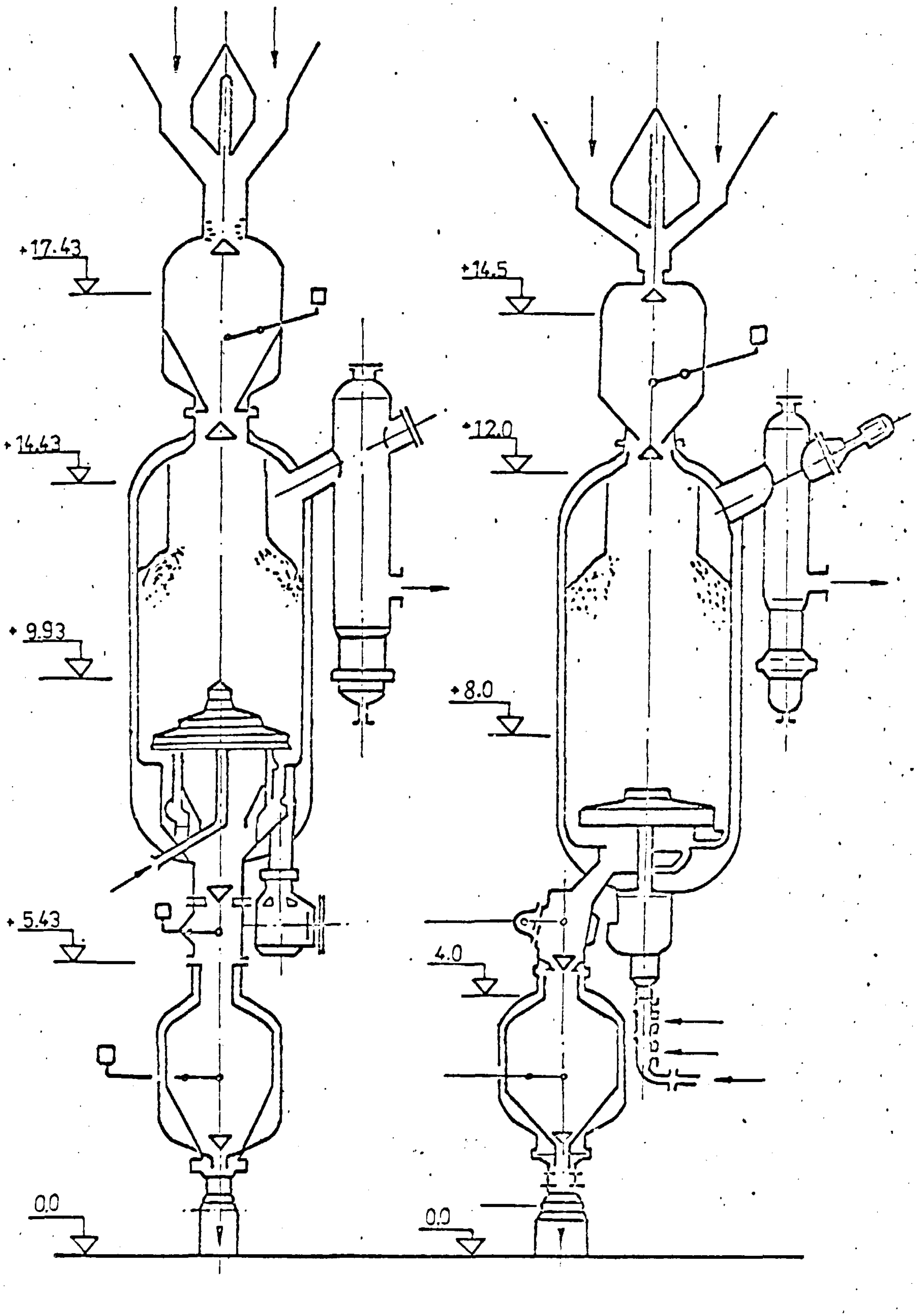


pressure gasifier „VŘESOVÁ"

pressure gasifier „ÚSTÍ"

Figure 2. DEVELOPMENT OF PRESSURE GASIFIERS IN [illegible]

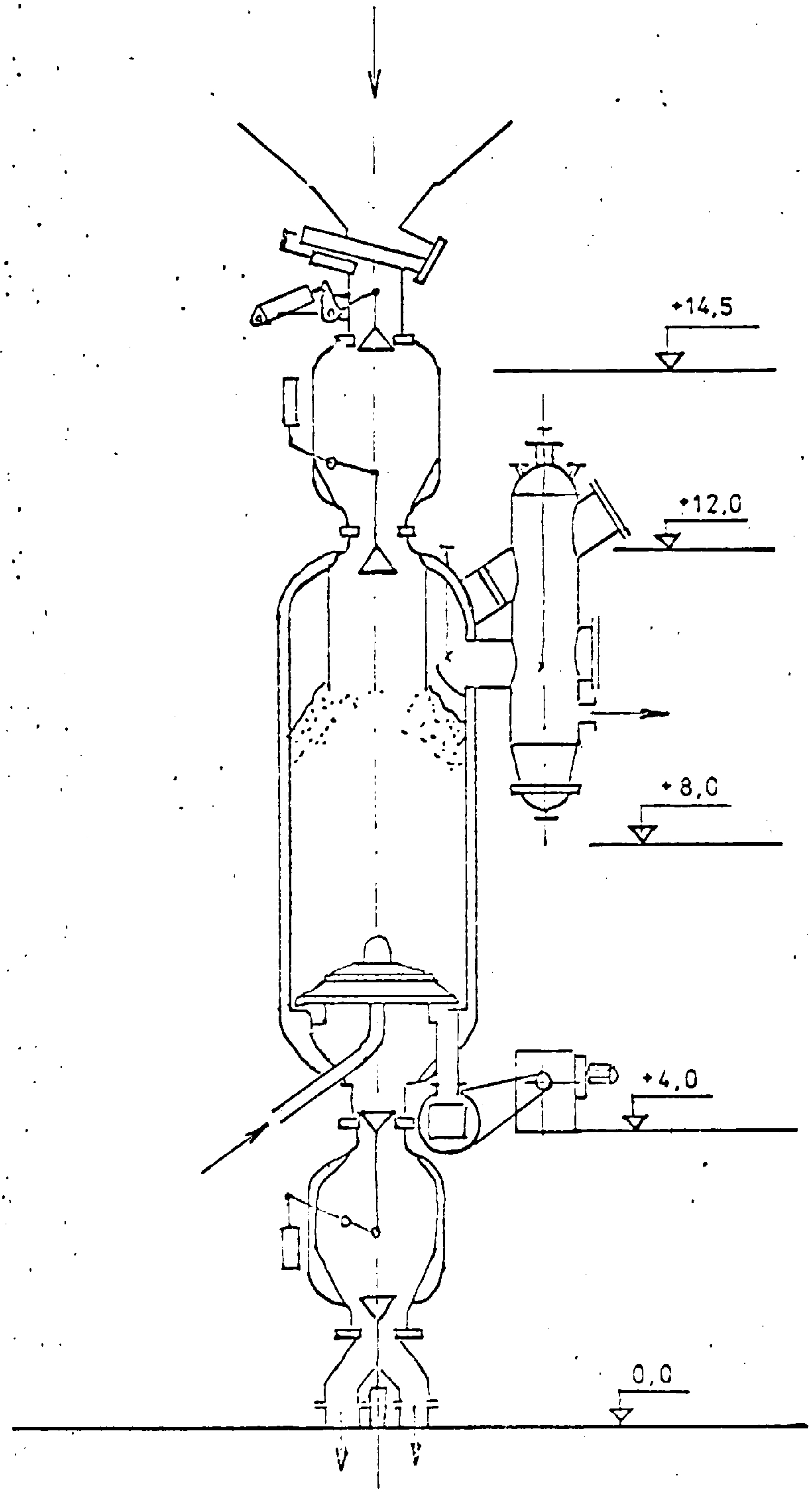


Figure 3. INNOVATED GASIFIER

Lecture III.

Prospects for the development of coal gasification

In connection with growing prices of petroleum and of natural gas in the seventies, the use of coal for the production of gas by gasification receives again much attention. Concerned are the increase in the operation reliability, economics of production, more efficient utilization as to time of existing machineries on the one hand and on the other hand the development of the further generation of an installation with a higher output presupposed to process a wider assortment of fuels including low-rank fuels.

Gasification as well as further treatment of gases is chosen also according to the required final product:

Town gas,
Synthesis gases,
Gas for power purposes,
Substitute natural gas.

The new development covers autothermal and allothermal processes, technologies of oxidizing and hydrogenating gasification, techniques of fixed bed, fluidized bed and of entrained bed gasification, chosen are mostly pressure variants.

A characteristic feature of the recent years is the limiting of the number of developed technologies, the same concerns the multistage technologies, mostly complicated and displaying high requirements for the machinery development as well as for their technological operation.

The fixed bed pressure gasification used for more than forty years is up to now the most widespread technology of coal gasification. This technology is advantageous for screened coal of a suitable grain size (e.g. 3-25 mm, 10-40 mm, 6-60 mm, 7-30 mm and others like that), for both lignites and bituminous coals if their FSI is lower than 4.

Important is also the ash content in dry state, attaining, for example in the operation in the CSSR on the average approximately 20 wt. %, nevertheless, coals with higher ash contents may also be gasified. In the case of these coals, besides the technical realization of the process when the strength of the coal processed is also significant, in particular the economic aspect is of great importance (higher specific consumptions of fuel and of the gasifying agent, lower yields of gas of a lower quality). According to our information in operation are the following gas plants: 1 in the SAR, 3 in Czechoslovakia, 1 in the GDR, and 1 in Yugoslavia. Also further countries, such as the USA, France, Greece, Turkey, Italy, Brazil, and China are interested in the realization of this technology.

The development, contingently the requirements for the constructions of pressure gas plants are aimed at the increase in the installation reliability and at the units of a larger diameter yielding higher outputs. In addition to initial full-scale units of 3 m o.d., gasifiers of 4 m o.d. are concerned and on an experimental scale also a prototype of the gasifier of 5 m i.d. is in operation.

Another trend of the development is the widening of the raw material base for gasification in order to process coals with higher ash contents and of a wider range of grain size including a higher portion of the undersize.

The development of an installation of further generation is aimed at the pressure variants of fluidized bed gasification and entrained bed gasification, as well as at further extension of fixed bed gasification.

The typical representatives of the pressure fluidized bed gasification are the processes Westinghouse and HTW developed in the USA and in the FRG respectively.

The Westinghouse process in its present final form is a fluidized bed one-stage gasification process performed at temperatures of 870-1060 °C, at an operating pressure up to

1.6 MPa. Coal is transported to the reactor pneumatically with a high velocity through the bottom of the reactor in a mixture with the gasifying agent. In the centre of the fluidized bed at the bottom of the reactor, zones with higher temperatures are formed in which ash agglomerates are formed and thus a reliable removal of ash with a minimum content of not reacted carbon is guaranteed. The process has been verified since 1975 in Waltz Mill, Pennsylvania, on the installation of an output 0.6 $t.h^{-1}$ or 1.5 $t.h^{-1}$ in air blown or oxygen blown gasification respectively. Processed was fuel containing 2-45 wt. % of ash, 3-24 wt. % of water, with FSI 0-9.

An industrial demonstration unit with a gasifier of 3 m diameter and 50 $t.h^{-1}$ output is under construction in Sasol (the South African Republic).

The HTW process of the Company Rheinbraun has been developed since 1978 to process reactive lignite of 0-4 mm grain size with the ash content A^d = 4-10 wt. %. The technology is performed at a pressure of 1.0 MPa, the experimental installation of 60 cm diameter processes 1.3 t of coal per hour (8 % of water) and produces 2200 m^3 of synthesis $gas.h^{-1}$. On the basis of pilot-plant results a demonstration plant has been designed to produce approximately 1 mld m^3 of synthesis gas per year for the production of methanol in four gasifiers. The first of them having a 2.7 m diameter and output 37 000 m^3 of $gas.h^{-1}$ should be put into operation in 1985. The construction of the plant is presupposed to be finished in 1988.

Pressure entrained bed gasification. Concerned is practically a further generation of the entrained bed gasification according to the Kopper-Totzek process. Also in this case the development is performed in several variants of which the most advantageous, from the standpoint of economy, are the processes Shell-Koppers and Texaco.

The Shell-Koppers process

A joint development carried out on the installation of an output 6.25 t of coal .h^{-1} was finished in 1981. Concerned is entrained bed gasification of finely ground coal (below 0.1 mm) with oxygen at a pressure of 3 MPa. The temperature in the centre of the flame exceeds 2000 °C, in the gasifier a temperature ranging from 1400 to 1600 °C is maintained so that ash is removed in liquid form from the bottom of the gasifier to the granulating water bath. In addition to proper grinding (relatively costly especially in the case of coals with higher ash contents), the coal should be dried and that bituminous coals to 1-2 % moisture, lignites approximately to 8 %. The firm Krupp-Koppers continues the development of the technology indicated as PRENFLO (Pressurized Entrained Flow Gasification) and prepares an operation of a unit with an output 1000 t of coal per day to produce synthesis gas.

The Texaco technology is based on the mode of entrained bed gasification, i.e. a mixture of finely ground coal with water (in the form of water suspension, containing 30-40 wt. % of water) is brought together with the gasifying agent into the gasifier by means of a burner. The fluid slag separated during gasification is removed through the bottom of the gasifier. The product obtained is either a synthesis gas or a gas for power purposes with a minimum content of hydrocarbons. In the USA this technology is verified on a pilot-plant installation of an output of 15 t of coal per day. In Holten (FRG) an experimental installation of the firms Ruhrkohle AG and Ruhrchemie AG, processing 6 t of coal per hour at a pressure of 4 MPa and at a temperature ranging between 1200 and 1600 °C has been in operation since 1978.

An advantage of the process similarly as in the case of all high-temperature processes consists in the minimum contents of higher hydrocarbons, phenols and tars in gas. Very advantageous are also coal grinding in water and slag removing to the water bath.

A further phase of the fixed bed gasifier development represents a RUHR 100 gasifier as well as a slagging gasifier developed by the British Gas Lurgi.

The experimental RUHR 100 gasifier of 1.5 m i.d. is intended for an operating pressure of 10 MPa; it has been in experimental operation since 1979. The gasifier has two gas outlets in the different heights of the shaft. The upper outlet is intended for the carbonization gas, through the lower outlet passes the gas from the gasifying zone. The gasifier is equipped with two coal hoppers. During the tests gasified were anthracite and weakly-caking bituminous coals with FSI 1-2. The main advantage of the process consists in the increase in the methane content in crude gas, exceeding as much as 16 vol. %, advantageous is also the increase in the specific output of the gasifier, exceeding 9000 m^3 of crude gas $.m^{-2}.h^{-1}$. In the further phase of development the construction of a demonstration unit with a gasifier of 3 m diameter is under consideration.

The British Gas Lurgi technology verified in Westfield (Great Britain) is intended for the production of synthesis gases and of gases for power purposes. This technology, in comparison with the classical pressure fixed bed gasification, differs by the fluid slag removal. Gasified are screened coals (as well as caking coals) with a potential dust admixture. The installation of 1.8 m i.d. processes as much as 12 t of $coal.h^{-1}$ at a pressure up to 3 MPa; it has been in verifying operation since 1974.

Another generation of the processes of gas production being developed at present presupposes the utilization of heat from nuclear reactors. The heat from nuclear reactors is supposed to be cheaper than that from coal. However, the realization of these processes will come into consideration by the end of the nineties.

In the FRG the utilization of nuclear heat is under consideration in the case of the hydrogenating gasification (HKV) and steam gasification (WKV) being developed at present.

As to hydrogenating fluidized bed gasification (HKV) performed at a pressure of as much as 10 MPa, under consideration is the utilization of heat from a high-temperature nuclear reactor through a helium circuit with an outlet temperature of 950 °C. The heating of the gasifying hydrogen will permit to save approximately 40 % of coal. With regard to the fact that hydrogenating reactions are exothermic, any further heat is not necessary to be brought into the gasifier. It is advantageous to use only the more reactive part of the coal mass and to process the remaining semi-coke by some other method.

In Wesseling (FRG) an experimental installation of 200 mm i.d. has been in operation since 1975, processing 400 kg of coal per hour at temperatures of 820-1000 °C and at a pressure of 5.5-9.5 MPa. It gasifies coal containing 12 % of water, of the grain size ranging from 0. to 2.5 mm. The gas produced contains 30-40 vol. % of CH_4, 1-2 % of CO_2 and about 5 % of CO. The residue is formed by hydrogen and water vapours.

In the last year the construction of a demonstration unit of 1 m i.d. should have been finished to process 10 t of dried coal and to produce 7800 m^3 of gas.

The steam gasification (WKV) is developed by Bergbauforschung in Essen. On the basis of laboratory results and experience obtained in 1976 a pilot-plant installation was constructed; its cross section is 0.8 x 0.9 m, and processes 8 t of coal per day.

The gasification is carried out by means of steam in a fluidized bed at a temperature of 840 °C and at a pressure of 4.0 MPa. The main reaction is that of carbon with steam in forming CO and H_2. The heat is brought into the reaction zone through a tubular heat exchanger immersed in the fluidized bed and thus a high efficiency of heat transfer is attained. By using this process caking coals with FSI 4-6 may also be gasified. The gas obtained is of the following composition: (in vol. %) H_2 - 47, CO - 15, CO_2 - 23, and CH_4 - 15.

Crude gas purification, conversion, cracking of tar vapours and conversion to methane

1. Crude gas purification

In general, the aim of the purification of gases is to remove undesirable components from gas and to treat it according to the purpose for which it is produced. For example, if gas produced from coal is used as a fuel gas in the vicinity of its source, removal of solid and liquid substances, such as dust, tar, and tar mist is sufficient. In the case of the long-distance gas distribution the requirements are higher in this respect since further components such as substances forming resins, naphthalene, nitrogen oxides, benzene, and water should be removed. For the purposes of synthesis catalyst poisons, in particular sulphur and nitrogen compounds should perfectly be removed.

In practice methods of gas purification are based on gas absorption in liquids or on gas adsorption on solid substances.

The principle of the equipment of the first group is gas scrubbing in a scrubber and regeneration during which a pure wash means is obtained again and absorbed gases are liberated. The absorption takes place usually at the lowest possible temperature and at a high pressure, whereas the regeneration is carried out at a lower pressure and at a higher temperature.

According to the mode of absorption and regeneration the following scrubbers are distinguished:

Physical scrubbers - the course of both scrubbing and regeneration is determined only by the pressure and temperature dependences of the gas and liquid dissolving equilibrium, Chemical scrubbers with thermal regeneration - during absorption of gaseous components a wash means forms a chemical compound which during regeneration is decomposed to a solvent and liberates the absorbed gas,

Chemical scrubbers with chemical regeneration - an efficient component of the wash solution is an inorganic or organic compound which may exist in several oxidizing degrees. With this compound the gas forms in the absorber a chemical compound which is oxidized during regeneration, mostly with air, so that a pure wash solution is obtained as well as a washed substance in the form suitable for further processing.

Adsorption - gases and vapours are adsorbed on the surfaces of solid substances.

The amount of the adsorbed substance is dependent on the adsorbent surface, pressure, temperature, and gaseous component concentration. For these purposes solid substances with the maximum specific surfaces (for example active carbon) should be used. For these purposes molecular sieves have recently been applied in the case of which the procedure of their production may affect the pores diameters and volumes and thus a higher selectivity of purification may be attained. Similarly as in the case of absorptive methods, in applying these methods favourable effects of a low temperature upon desorption are also found, on the contrary, a higher temperature favourably influences the desorption of gases during the regeneration of an adsorbent.

A final product of all our pressure gas plants is town gas and owing to this the diagram of the gas purification is very similar in all these plants.

The crude produced gas is successively cooled by phenol water injection in the precooler and further in waste heat boilers, successively to 120-130 °C. At the same time steam of 0.35 and 0.05 MPa overpressure is produced in the boilers.

Gas is then cooled in the system of counter- and co-current water coolers to a temperature of 25-35 °C and the condensate obtained contains, besides water, also tar, ammonia, and further organic compounds.

In the case of a following crude gas shift conversion the crude gas is withdrawn with a temperature of 160-170 °C already behind the waste heat boiler of the first stage. The purpose of the crude gas shift conversion constructed as a test line, is to reduce the toxic carbon monoxide content in gas below 5 vol. %. (Detoxication is discussed in more detail in the further chapter.)

Crude gas is purified by scrubbing with deeply cooled methanol in the installation consisting of the crude gas scrubbing, of the independent cooling system Linde, and of the complex regeneration system of methanol.

Scrubbing as well as cooling is carried out at four stages, in the case of the selective scrubbing of hydrogen sulphide at five stages. At the first stage gas is cooled by condensate injection to +10 °C and stripped of ammonia, hydrogen cyanide, and crude benzol. At the following stage gas is cooled to -20 °C by using the methanol/water mixture, a part of gases is removed and crude benzol is separated. (Hydrocarbon condensates from cooling are treated by distillation to obtain an aromatic condensate.)

Gas is further cooled in the main scrubber, at the last stage by injecting methanol at a temperature below -60 °C and thus the most important portions of CO_2 and H_2S are removed. (In the case of the selective variant, the removal of H_2S and CO_2 is separated.) During scrubbing gas is simultaneously dried to a dew point of about -50 °C. In the absorber for final scrubbing the so called fine final purification with methanol is carried out at a temperature of -50 °C.

According to actual technological conditions the pure gas contains 4-12 vol. % of CO_2 and 5-40 mg of H_2S per 1·m^3. Its quality is further treated by adding nitrogen or air and natural gas to attain the standardized value of town gas.

Gas condensates from the production are processed in the dephenoling station. After pre-purification, when lighter oils and tars are separated, phenol water is saturated with expansion gas containing a high portion of CO_2 and thus further portions of tars are separated. A phenol condensate is obtained by butyl acetate extraction followed by its distillation. From the dephenoled water ammonia in the form of ammonia liquid is obtained. The dephenoled water is used for ash transport and thus degradation of phenols takes place. Final purification of water is carried out by means of microorganisms in the biological treatment plant.

2. Crude gas conversion in pressure gas plants

Detoxication of gas in pressure gas plants, i.e. reduction of the toxic carbon monoxide content after the inevitable removal of tar, coal dust, and sulphur compounds may be solved by using an iron-chrome catalyst, of course, with an additional admixture of high-pressure steam to a pure gas in order to reach the required degree of conversion.

These facts as well as economic aspects supported a proposal for the development of crude gas conversion. This process is based on the potential use of steam contained in crude gas in such a quantity that considerably exceeds the stoichiometric steam consumption for conversion taking place according to the following equation

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \pm 41.2 \text{ kJ}$$

when a suitable catalyst is present already from a temperature of 350-400 °C.

In Czechoslovakia researches into a catalyst were dealt with already during the period 1968-1971. These studies resulted in the development of a catalyst based on cobalt and molybdenum and later produced and marked as CHEROX 35-06. It was verified in a laboratory reactor for 1 l of catalyst. A laboratory research proved that crude gas saturated at a temperature of 165-170 °C and containing 2-10 g of H_2S per 1 m^3 is suitable for conversion. The optimum working temperature was defined in the range 400-440 °C, the degree of conversion during nearly a 2000 hours operation continuously reached the value of about 70 %.

Successful laboratory tests of the catalyst were followed by its verification in a prototype unit constructed for 30 000 m^3 of crude gas per hour, the diagram of which is presented in Figure 1.

In a spray scrubber solid particles and unsuitable liquid products were removed from the crude gas produced by pressure gasification of coal. Then the crude gas with a temperature of 165-180 °C was led through the system of exchangers where it was heated up to 325-360 °C. In the prereactor the last residues of impurities were removed. Behind the first reactor the gas with a temperature of 410-420 °C was cooled in the exchanger 4 to 380 °C and then it was led to the reactor II. In the exchangers and then in the cooling line the converted gas transferred successively its heat to the crude gas. After compression it was purified together with other gas by methanol scrubbing. In the conversion unit gas containing on the average 3.4 vol. % of carbon monoxide was obtained and thus the planned goal of the task, i.e. to produce gas with the CO content below 5 vol. %, was exceeded. In the full-scale installation the degree of CO conversion ranged between 61 and 72 %.

3. Cracking of tar vapours

The aim of the experimental studies carried out in the pressure gas plant Vřesová was to utilize especially the so called "tar sludges" obtained in separating the tars of the following composition:

Water content	30-70 wt. %
Tar content	10-50 wt. %
Solid portion	5-25 wt. %

The solid portion is formed by coal grains mainly below 2 mm. The installation for processing the sludges consists of three functional parts: the mixing tank, the circulating loop, and the dosing apparatus for individual gasifiers. Sludges are injected into the layer of coal in the gasifier retort. The injection per one gasifier ranges between 200 and 400 $l.h^{-1}$ at the gasifier output 1200-1600 $m^3\ O_2.h^{-1}$. In injecting, the contents of combustible components in crude gas slightly increased (hydrocarbons, hydrogen, carbon monoxide) and the gross calorific value increased by as much as 200 $kJ.m^{-3}$.

At these parameters the gasifier operation was steady, without any failures.

Tests were carried out with light tar as well as with tar sludges. While the light tar transport to the gasifier caused no difficulties, in the case of tar sludges, with regard to the raw material composition and its variation, the transport was often interrupted due to clogging the traffic roads.

4. Methane production from pressure gas

The basic reactions taking place during the methanation of gas from gasification are as follows:

$$CO + 3H_2 \longrightarrow CH_4 + H_2O$$

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

The course of methanation reactions is decisively affected by the presence of a catalyst. According to literary data these methanation reactions on active catalysts start at temperatures of about 200 °C. The optimum operating temperature ranges between 250 and 350 °C. Above this limit the undesirable carbon dioxide, hydrogen, and carbon are formed.

There is a problem caused by a large amount of heat liberated during the reaction, as well as a problem connected with its removal. For this reason new types of reactors are suggested, for example tube bundles with catalyst applied to tube surfaces, reactors with a catalyst fluidized bed, reactors with catalysts suspended in liquid, etc.

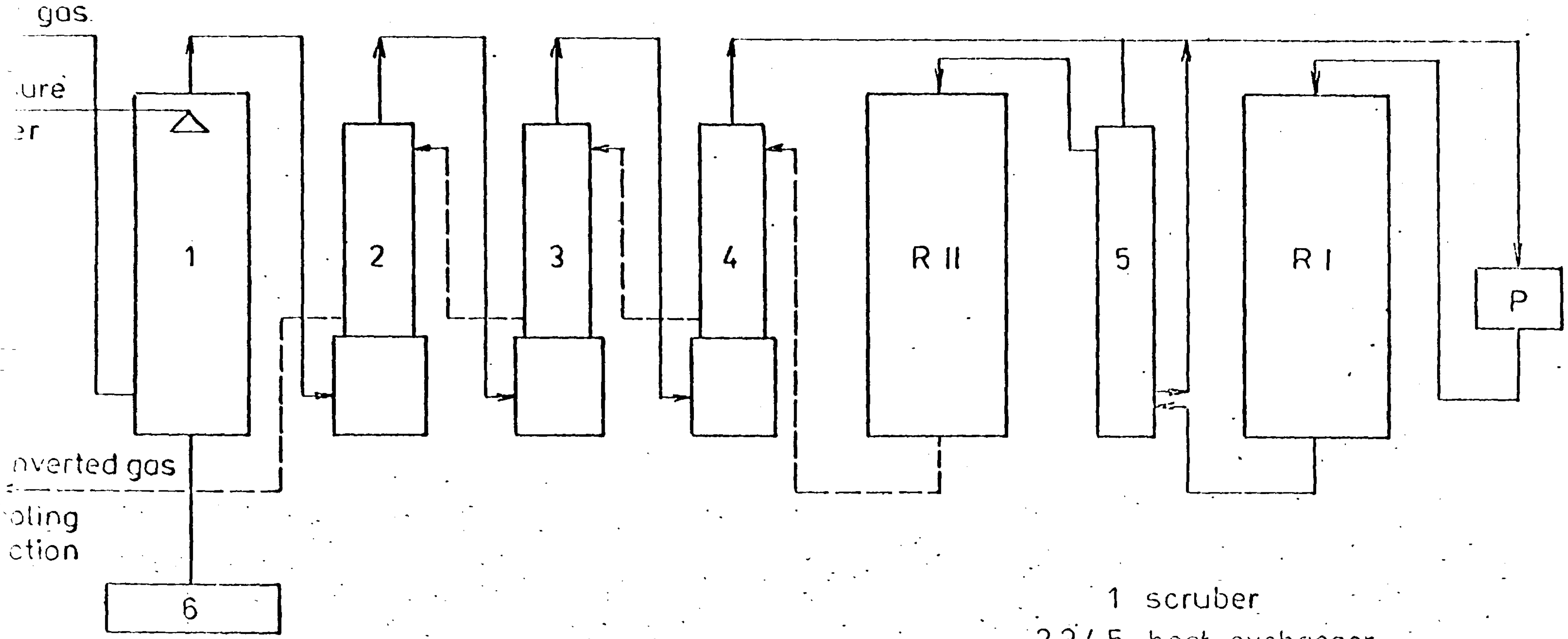
The development of full-scale catalysts was aimed at precipitated catalysts containing nickel (and that above 30 %) as an active component with promoters such as U_3O_8, Cr_2O_3, K_2O, MgO and others.

It is also important to secure a high purity of inlet raw materials, namely as far as low contents of sulphur compounds below 1 ppm are concerned.

In applying methanation at pressure gas plants, gas may be treated by shift conversion and by CO_2 scrubbing and thus the required $CO:H_2$ ratio approaching the value 1:3 can be obtained and after methanation and treatment substitute natural gas (SNG) can be prepared.

With regard to the arrangement of pressure gas plants, gasified coal and to outlooks for the development in Czechoslovakia, conversion of gas plants to the SNG production is not under consideration and owing to this these problems do not receive much attention.

RAW GAS CONVERSION



1	scruber
2,3,4,5	heat exchanger
6	condensate
P	prereactor
RI,RII	reactor